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Health Effects of Coal Technologies: Research Needs

MITRE Corp.
McLean, VA

Prepared for

Federal Interagency Committee on the Health and
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McLean, VA

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Health Effects of Coal Technologies: Research Needs

Sponsored by the

Federal Interagency Committee on
the Health and Environmental Effects
of Energy Technologies

Department of Energy

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The MITRE Corporation/Metrek Division
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This report provides an assessment of health effects research needs associated with the coal-based technologies of conventional coal, chemical coal cleaning, fluidized bed combustion, magnetohydrodynamics, coal-oil mixtures, cocombustion with municipal solid waste, and in situ coal gasification. Background information providing technology descriptions, and characterization of air emissions, water effluents, and physical disturbances associated with these technologies is provided in another report (NTIS # PB 299 040; Committee # DOE/HEW/EPA-04).

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FOREWORD

In his 1977 Environmental Message, President Carter directed the Administrator of the Energy Research and Development Administration, the Secretary of Health, Education, and Welfare, and the Administrator of the Environmental Protection Agency to establish a joint program to identify the health and environmental problems associated with advanced energy technologies and to review the adequacy of present research programs. In response to the President's directive, representatives of the three agencies formed the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies. As a result of reorganizations, the Committee currently is composed of representatives of the Department of Energy, the Department of Health and Human Services, and the Environmental Protection Agency. The MITRE Corporation, Metrek Division, is the Executive Secretariat for the Committee.

The goals of this Committee are to review and identify specific health and Environmental issues and potential problems associated with the development and commercialization of conventional and advanced energy technologies, to identify the information required to resolve the uncertainties of relevant impacts, to specify research projects to provide such information, and to review the adequacy of current Federal research with respect to these projects. To attain these goals, the Committee is sponsoring a series of workshops, establishing working groups, and initiating other approaches to address the health and environmental consequences of energy technologies.

This report was prepared by the Health Effects Working Group on Coal Technologies for the Committee. In this report, the major health-related problems associated with conventional coal mining, storage, transportation, and combustion, and with chemical coal cleaning, in situ gasification, fluidized bed combustion, magnetohydrodynamic combustion, cocombustion of coal-oil mixtures, and cocombustion of coal with municipal solid waste are identified. The report also contains recommended research required to address the identified problems.

Background information on the technologies addressed in this report as well as those of coal gasification and liquefaction may be found in documents previously released by the Committee and listed on the last page of this report. In the near future, the Committee intends to release additional advisory reports relating to ecological effects and transport and transformation research needs associated with coal technologies. The results of these and other activities sponsored by the Committee should provide a basis for strengthening the Federal Program for ensuring safe and timely development of our energy resources.

THE FEDERAL INTERAGENCY COMMITTEE
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EFFECTS OF ENERGY TECHNOLOGIES

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1.0 EXECUTIVE SUMMARY

1.1 Introduction

With increased emphasis being placed on coal as a source of energy, the concern over potential impacts on human health from this technology has increased as well. The Federal agencies responsible for funding energy-related health research are aware of this increased level of concern and are improving and updating their programs to assure the timely and safe development and expansion of coal-related technologies. To this end, and in response to the 1977 Presidential mandate, the Department of Energy, the Department of Health and Human Services, the Environmental Protection Agency have formed the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies. The report that follows has been prepared by the Health Effects Working Group on Coal Technologies, as advisory body to the Committee. The objectives of the Working Group are to identify the potential human health effects associated with the conventional coal cycle and advanced coal processing and combustion technologies and to suggest relevant research needs. The technologies considered in this report include:

- conventional coal (mining, transport, storage, combustion)
- chemical coal cleaning
- in situ coal gasification (a reevaluation of previous work)
- fluidized bed combustion

- magnetohydrodynamic combustion
- combustion of coal-oil mixtures
- cocombustion of coal with municipal solid waste

1.2 Approach

The Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies selected the following approach to facilitate identification of health effects and related research needs for the conventional coal cycle and for advanced coal processes. A working group of experts in various health-related fields was identified by the cochairmen who had previously been selected by the Committee. This group was given a day-long presentation on the energy technologies themselves. This background information is also presented in a companion report entitled Health and Environmental Effects of Coal Technologies - Background Information on Processes and Pollutants (DOE/HEW/EPA-04). Following these presentations, the group met to define the scope and organization of the product they would produce and to assign the primary authorship of various sections. The panel members then reconvened several months later after first drafts had been prepared and circulated. These were read, revised, and combined as necessary. At this point the report was submitted to a rigorous editing and was then recirculated for comments. The result of this group's effort is the following report.

The Health Effects Working Group was asked by the Committee to analyze the coal fuel cycle and, in light of the current state of knowledge, to indicate potential problems that should be studied in greater detail to identify and assess health impacts which may be associated with use of this natural resource. This charge included identifying safety hazards as well as the biological effects of pollutant exposure. The following are caveats: 1) Effects in these areas were considered for both the general and occupational populations, but emphasis was placed on detection of possible occupational effects since they may serve as indicators of more subtle effects in the general population. 2) In the assessment of the potential health effects and determination of research needs contained within this report, it was assumed that Best Available Control Technology as defined under the 1977 Amendments to the Clean Air Act would be in effect.

In 1977 a Committee on Health and Environmental Effects of Increased Coal Use headed by Dr. David Rall (Director, National Institute of Environmental Health Sciences) submitted a report to the Secretary of Health, Education, and Welfare (Rall 1977). That committee dealt primarily with broad problems relating to conventional coal combustion. Some of the areas suggested by the Rall Committee as requiring research have not yet been adequately addressed; therefore these were reaffirmed by the Health Effects Working Group and appear among their recommendations. The Interagency Health Effects Working Group has also tried to focus on details of the coal technologies to identify particular unit processes, pollutants, and effects likely to be of concern rather than on broad problems.

Based on a preliminary identification of problem areas, need for the following types of research was expressed:

- Pulmonary Effects
- Skin Effects
- Gastrointestinal Effects
- Behavioral and Neurotoxic Effects
- Other Systemic Effects
- Carcinogenic, Mutagenic and Reproductive effects

In addition, the Health Panel felt that the whole area of exposure assessment should be addressed both in general and for the individual technologies. One means of assessing exposure, epidemiological studies, could be used to assess many of the types of effects listed above.

Of the technologies being considered by the Health Effects Working Group, some are commercially available while others are entirely developmental. This greatly affects the amount of data available and hence the nature of the research requirements. More basic research is needed for the newer technologies to identify potential problem areas while for coal mining or combustion research should be focused on identifying dose response relationships, pollutant interactions, and reasons for susceptibility to identified pollutants. Particular emphasis is placed on those technologies expected to reach commercialization in the next 5-10 years.

The Working Group recognized the existence of generic problems that relate to many aspects of coal technology as well as technology specific problems. For example, coal dust exposure occurs during mining and is also associated with those combustion technologies that require preliminary crushing and grinding of the coal. Chapter 3 of this report focuses on these more generic exposure issues while Chapter 4 addresses the coal sub-technologies individually and defines the health hazards unique to each sub-technology. This same dual concern is existent in the organization of Chapter 6 which focuses on particular types of effects both generically and then as a function of the sub-technologies. The Working Group felt that this organization would facilitate research planning. It permits identification of the specific sub-technology research needs that can be emphasized or de-emphasized in parallel with national and agency priorities while permitting identification of generic research that should be allowed to proceed unaffected by these minor shifts in program emphasis.

The Working Group also strongly recommends that there be a long-term commitment to characterization of the chemicals and mixtures associated with coal utilization technologies. This characterization should be an iterative process from bench scale to commercial-sized plants. In a coordinated effort, the health and safety effects of these characterized materials should be identified. This will require continued close interaction between health scientists and those responsible for process design to assure that health effects of technology developments will be addressed in a timely manner.

The Health Effects Working Group has included in this report at the ends of the relevant textual sections over 160 recommendations for coal technology-related research.

The following list represents a summary of some of the high priority research areas recognized by the Health Panel.

- The effect on worker's health from the increasing use of diesel powered machinery in mines should be investigated.
- Tests need to be developed to more rapidly predict placental transport of pollutants and subsequent reproductive dysfunction, especially for metalloids.
- Because increased coal combustion will result in higher levels of volatized trace metals and carbon monoxide, the potential for low level, long-term exposure to result in behavioral effects should be investigated.
- Epidemiological studies of both workers and populations living near various coal combustion facilities are needed to define the impact on human health, especially regarding cancer and lung disease, from the use of coal as a fuel.
- Research is needed to identify indicator compounds to be used for exposure assessment and as predictors of health effects including cancer.
- Coal workers' pneumoconiosis remains a significant health problem associated with coal mining. Research is needed to increase understanding of the disease process and to devise means of minimizing its effects.
- The magnitude of the impact on the health of the general population from radionuclides released as a result of coal combustion is not known and should be more thoroughly investigated.
- The effects of the following technology-specific pollutants/agents need to be investigated:

  - microwaves from the G.E. coal cleaning process
  - metal carbonyls from the Magnex coal cleaning process
  - acid mists from the PETC and JPL coal cleaning processes
  - magnetic fields from magnetohydrodynamic combustion
  - chlorine and cadmium from cocombustion of coal and refuse derived fuel.

- Characterization of air emissions, water effluents, and solid wastes from the conventional coal cycle and from advanced coal combustion technologies is needed to serve as input to exposure and toxicological assessments.

- Monitoring can be used to determine exposure to coal-related pollutants; but additional development of personal samplers and area monitors is required, especially for organometallics.

- Because coal combustion results in the generation of large amounts of solid waste, monitoring should be instituted to ensure that toxic substances do not leach from the disposal sites into groundwater, a potential source of drinking water.

- Mining and transportation accidents associated with utilization of the coal resource are significant and means must be sought to eliminate the causes of these accidents.

- General research is needed to define the biological mechanisms and the disease processes associated with effects to the skin, gastrointestinal tract and other organ systems (e.g., liver, kidney, heart) following exposure to coal-related pollutants.

- Techniques are needed to more rapidly assess the carcinogenic, cocarcinogenic, and promotor activities of complex pollutant mixtures associated with coal combustion technologies.

- High noise levels are associated with many of the coal technologies and means of preventing otological damage need to be developed.

2.0 BACKGROUND

2.1 Overview Information on U.S. Coal Utilization

All phases of the coal cycle, from extraction, through processing, conversion, and power generation, to final disposition of residual wastes, produce environmental/occupational impacts that could limit the utility of domestic coal resources. These problems can be controlled, but at a cost. Table I indicates some of the environmental/occupational problems associated with the major phases of the extraction, processing and utilization of coal considered in this report.

Estimation of the health effects resulting from the different phases of the coal cycle will depend upon the amount and type of coal processed, the uncontrolled rate of emission, the process used and the control technology adopted. The projected increase in coal consumption during the period 1975 to 1985 is summarized in Table II. The majority of the coal is used by the utility industry, a situation which is expected to continue at least through the year 2000 (Figure 1).

Most of the coal used by the utility industry will be burned in conventional pulverized coal boilers modified to incorporate advanced pollution control devices to reduce the emissions of nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulates. Several advanced energy conversion technologies are currently at the bench or pilot-scale stage of development. Estimates (Cain et al. 1979) of possible rates of commercialization for these technologies are shown in Figure

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TABLE I

MAJOR POLLUTANTS, DISTURBANCES, AND CONTROL TECHNOLOGIES ASSOCIATED WITH THE COAL ENERGY CYCLE

EXTRACTION/TRANSPORTATION/STORAGE

Underground Mining

Air Particles
Noise/Vibration   Control/Ventilation
Diesel Exhaust

Acid Drainage------Contain/Neutralize
Solid Waste--------Well-Managed Landfill

Surface Mining

Runoff Solids
Acid Drainage
Sediments ----Control/Treatment of Runoff
Air Particles   Well Managed Mine
Solid Waste   Restoration and Revegetation

Coal Refuse Piles

Particulates, CO
NO_x, SO_x, HC's

Storage

Run-off-------neutralization/sedimentation

Transportation

Fugitive dust
Engine exhaust emissions (truck, train)
Spills (barge, pipeline)
Water Contamination (pipeline)

Underground Gasification

Fugitive/Accidental
Release of Toxins
Carcinogens
Runoff and Leaching

PROCESSING CONVERSION

Physical Coal Cleaning

Air Particles------------Dust Control
High sulfur Solid Waste--Recover Sulfur
Runoff Solids------------Contain
Acid Drainage------------Contain/Neutralize
Solvents-----------------

Chemical Coal Cleaning

Magnex, Syracuse, Meyers, PETC, GE,
Battelle, JPL, KVB, Amers, Arco.,...
Emissions and control strategy are specific to the individual processes

GENERATION AND WASTE DISPOSAL/CONTROL

Combustion (Conventional, MHD, Fluidized Bed, Coal-Oil Mixture)

Sulfur Oxides---------Scrubbers, in-situ Capture
Cleaned Coal
Nitrogen Oxides----- Scrubbers Combustion Modification. Flue Gas Treatment.
Flyash and Smoke Particles---------- Cyclones, Baghouses, Electrostatic Precipators Scrubbers
Solid Waste(Ash)---- Well-Managed Landfill
Spent sorbent------- Well-Managed Landfill, Regenerate
Trace Toxic Metals - Baghouse, Scrubbers
Organic Compounds - Baghouse, Scrubbers
Cleaned Coal
Radioactive Compounds

Cocombustion with Municipal Solid Wastes

Trace metals, pathogens, HCl, additional coal to the pollutants expected from coal combustion

---

*Underground Gasification represents components of both the extraction and processing steps of an energy technology sequence

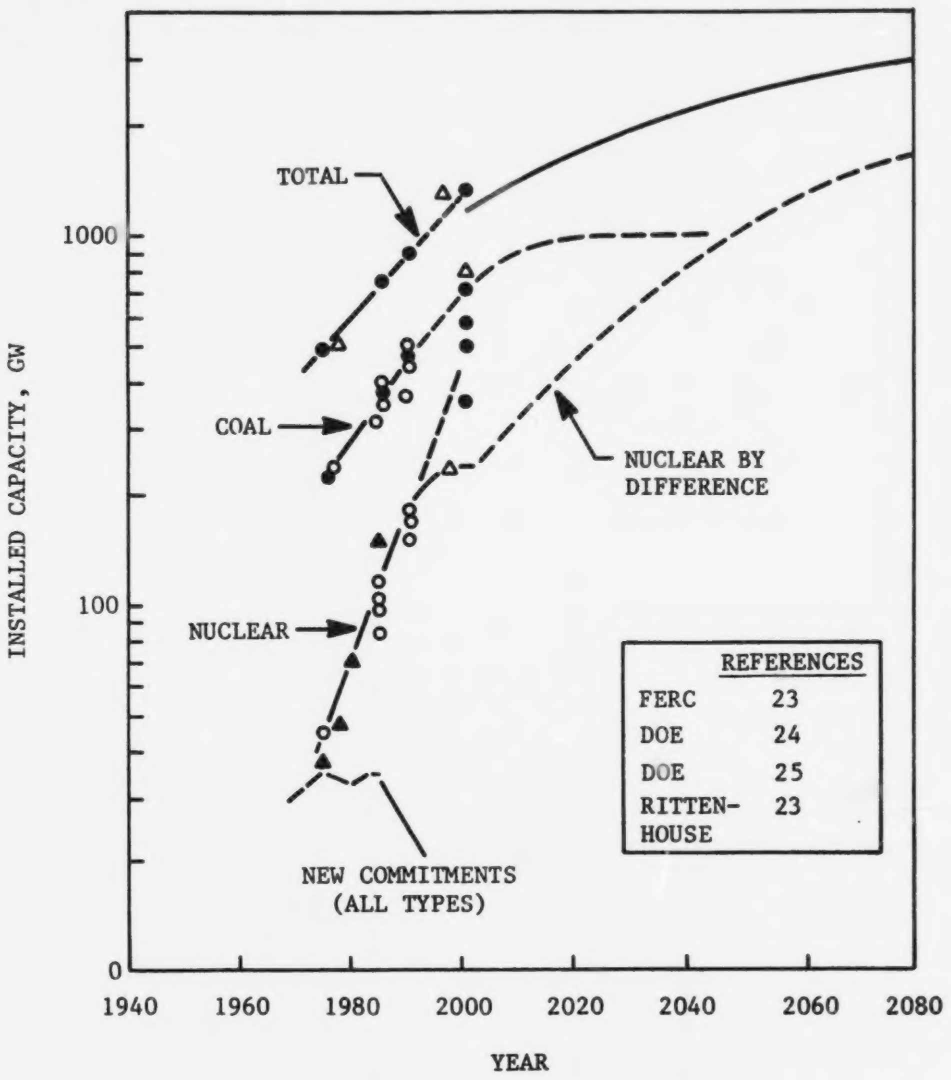
TABLE II COAL CONSUMPTION FORECASTS**
(million tons)

	Utility	Industrial	Metallurgical	Export	Other	Total
1976 Base Case	444	65	85	65	6	665
1985 Estimates						
Business as Usual	763	101	105	90	7	1066
NEP (1977 National Energy Plan)	779	278	105	90	13	1265
House/Senate Conference	779	198	105	90	13	1185
National Coal Association	820-850	130-160	80-110	80-110	7	1117-1237
American Gas Association	680-705	170-375*		-	-	850-1080

Sources: *Combines industrial and metallurgical consumption.

Business as usual and NEP, official DOE estimates; House/Senate Conference is an information guesstimate by DOE staff; NCA most current staff estimate; and AGA based on very restrictive interpretations of Clean Air Act Amendments (PL 95-95).

Source: Rall 1977



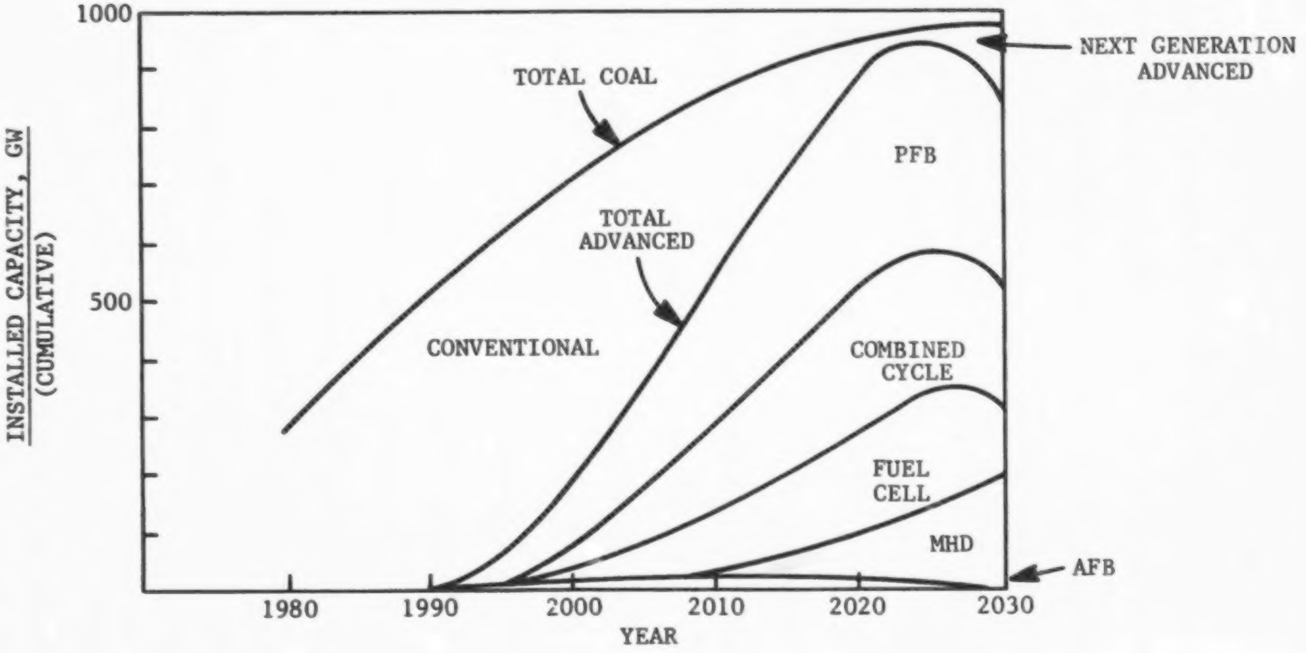
SOURCE: Cain, et al 1979

FIGURE 1
ELECTRIC GENERATING CAPACITY PROJECTED FOR U.S.

2. Based on these projections, emissions through 1990 will be primarily from pulverized coal fired boilers; atmospheric pressurized fluidized bed combustion is the only advanced technology that may have an impact on national emissions prior to 2000 (see Table III).

The growth in coal use by the industrial sector is much less certain and is strongly dependent upon the implementation of the provisions in the National Energy Act aimed at promoting the industrial replacement of imported oil by coal. Shipments of coal to industrial users were decreasing up to 1975 (from $97\text{x}10^6$ tons/year in 1969 to $52\text{x}10^6$ tons/year in 1975). Most of this coal was used in stoker-fired boilers with the balance used in larger pulverized coal-fired units. The trend in coal use by industry has been reversed, and one estimate (Waterland et al. 1979) shows an approximate doubling of the use of coal in package boilers from 1978 to 2000 (see Figure 3). Atmospheric pressure fluidized beds have a major potential for displacing stoker-fired boilers in the industrial sector if demonstration plants currently under consideration or construction prove the technology to be economically viable. It is estimated (Daman 1979) that atmospheric pressure fluidized beds will be burning the equivalent of 0.99 quads/year ($=125\text{x}10^6$ tons/year) by the year 2000 (see Figure 4).

The increase in coal utilization projected above is a consequence of a normal growth in coal utilization in regions of the U.S. that have traditionally relied on coal as a fuel and by major



SOURCE: Cain et. al., 1979

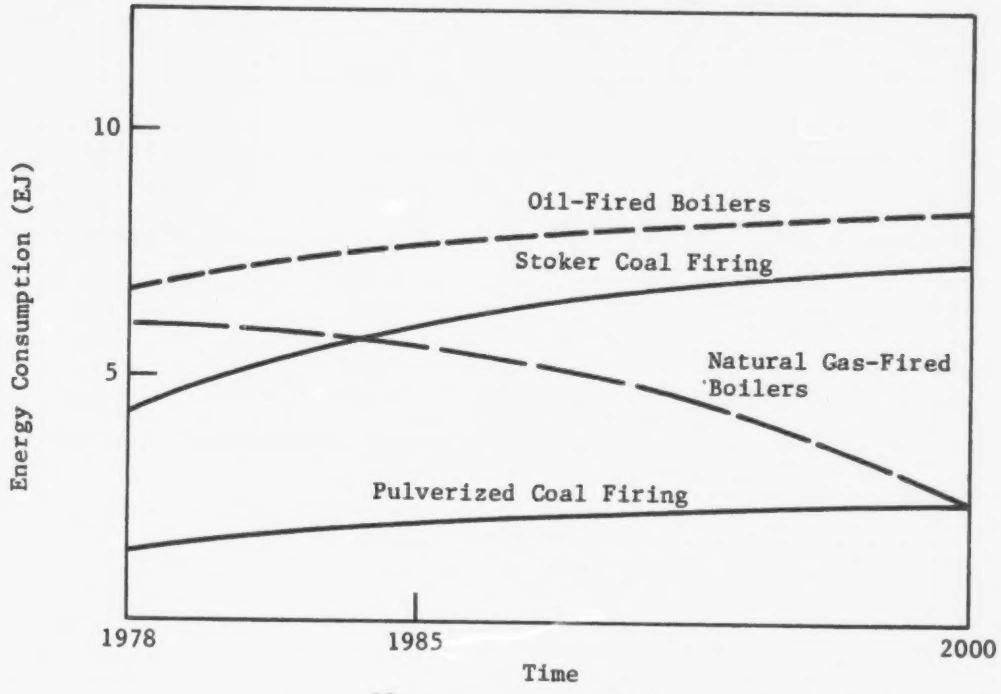
FIGURE 2
PROJECTED COAL-BASED ELECTRICAL GENERATING CAPACITY TIGHTER STANDARDS

TABLE III ESTIMATE OF COAL-FIRED FBC POTENTIAL

INDUSTRIAL COAL UTILIZATION

Year	Cumulative Number of Industrial FBC Steam Generators	Quads/Yr	1000 bbl/day of Oil Equivalent
1980	7	0.01	5
1985	200	0.29	136
1990	685	0.99	462
1995	1170	1.69	793
2000	2050	2.97	1400

Source: Daman 1979.

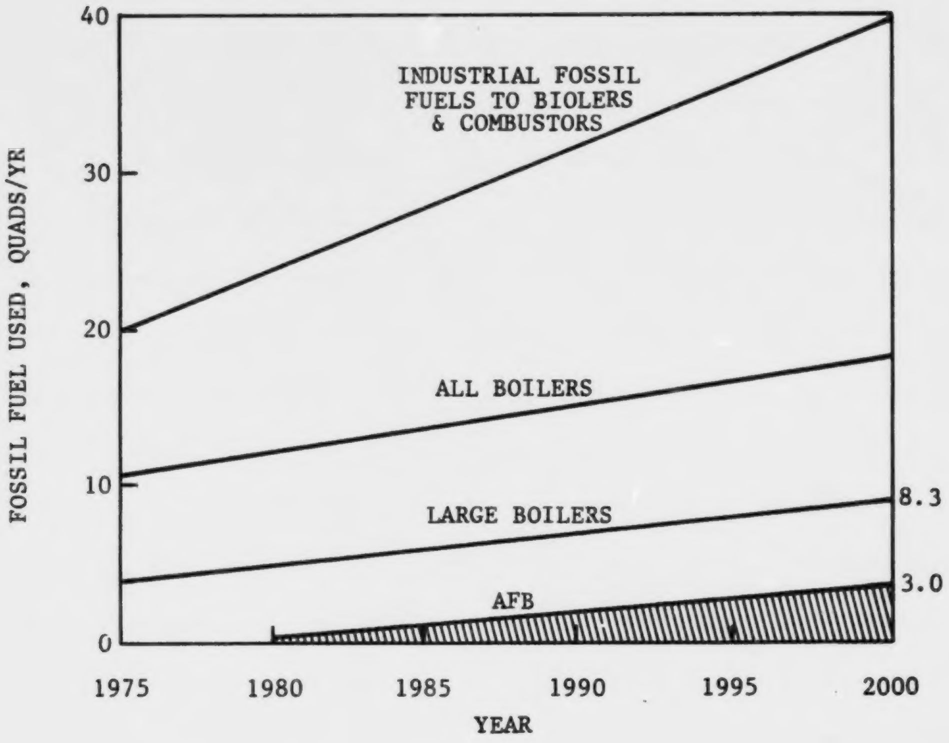


1ET = 10^{18} J/Year = 40 x 10^6 tons isul/year

NOTE: Only coal consumption is shown by equipment types. The values of the energy consumption in this Figure have been revised but the predicted trend toward increased coal consumption by the industrial sector remains unchanged. (H.B. Mason, personal communication, March 1980).

Source: Waterland et al. 1979

FIGURE 3
NATIONAL ENERGY CONSUMPTION AND EQUIPMENT TRENDS FOR PACKAGED BOILERS*



Source: Daman, 1979.

FIGURE 4
INDUSTRIAL ATMOSPHERIC FBC MARKET FOR LARGE STEAM GENERATORS

increases in utilization of coal in certain regions, primarily the West and South; where little use of coal has been made in the past.

2.2 Coal Resource Description

The potential emissions from coal are strongly related to the concentration of trace species present in the carbonaceous matrix which constitutes the bulk of the coal. The elements of major concern are sulfur which is responsible for the emissions of SO_x, nitrogen which contributes a major fraction of the NO_x emissions, and other inorganic constituents, especially trace metals.

The organic carbon (C) and hydrogen (H) contents of coal are predominantly in the form of aromatic and hydroaromatic groups and to a lesser extent in aliphatic sidechains. The aromaticity of a coal increases with rank. The oxygen (O), sulfur (S), and nitrogen (N) are present in both heterocyclic groups and in functional groups such as -OH, -COOH, -O-, -SH, -S-, -NH, $-NH_2$, -N=. The compounds formed during the cleavage of linkages during thermal processes will bear a strong relation to the structure of the parent coal.

Most of the inorganic coal components were deposited either as sediments in the original bed or as secondary materials during the formation of the coal; however, some of the trace or minor elements in coals were probably present originally in the plant material from which the coal was originally formed. The most abundant inorganic elements in coals (excluding S, N, and O) are listed in Table IV. These are the elements that, for the most part, form the major

TABLE IV

MAJOR INORGANIC ELEMENTS IN COALS

ELEMENT	RANGE (WT%)
SILICON	0.6 - 6.1
IRON	0.3 - 4.3
ALUMINUM	0.4 - 3.1
CALCIUM	0.1 - 2.7
POTASSIUM	0.1 - 0.4
MAGNESIUM	0.1 - 0.3
TITANIUM	0.0 - 0.3
SODIUM	0.0 - 0.2

Source: Wewerka et al. 1976

minerals found in coals. These minerals fall into the four main classes listed in Table V. They are the aluminosilicates (sodium (Na), potassium (K), aluminum (Al), silica (Si)), the sulfides (Iron (Fe)), and the carbonates (calcium (Ca), magnesium (Mg), and iron (Fe), and silica). Generally, the aluminosilicates (clay materials) and quartz tend to be chemically stable. Neither is volatile or likely to be leached from the coal. During combustion, these minerals will fragment and fuse to form small particles (flyash) that mix with the stack gases. The carbonates also form ash during combustion. In addition, they are partially water soluble and may be leached out of coals or wastes. These materials can also contribute significantly to the particulate occupational exposure. Underground coal mining may generate very high levels of airborne dust unless adequate controls are instituted. There can also be considerable noise and vibration and the exhaust from diesel engines can additionally contribute to the occupational exposure in the few mines in which they are used.

Among all of the coal constituents, environmental contamination caused by pyritic materials is the most severe. At ordinary temperatures, the sulfides are not particularly soluble or volatile, but when pyrite (or marcasite) is exposed to atmospheric conditions, it can interact with air and water at ambient temperatures to produce soluble iron sulfate and sulfuric acid (Wewerka et al. 1976). This reaction of the iron sulfides in coals is, in fact, responsible for

TABLE V

MAJOR MINERALS IN COALS

ALUMINOSILICATES (10-80 WT%)	SULFIDES (0-40%)
ILLITE KAOLINITE MIXED LAYER CLAYS	PYRITE MARCASITE

SILICA (0-20 WT%)	CARBONATES (0-10 WT%)
QUARTZ	CALCITE DOLOMITE SIDERITE

Source: Wewerka et al. 1976

the formation of acid mine drainage, a most serious water-pollution problem. Also, at combustion temperatures, the sulfur in the iron sulfides (along with added amounts of organic sulfur) is oxidized to sulfur dioxide (SO_2), a significant air contaminant associated with the burning of coal.

In addition to these major inorganic elements, coals also contain a wide variety of trace or minor elements. An indication of the concentration levels of trace metals and variation in composition between coals is provided by the analyses reported for 101 coals by the Illinois State Geological Survey (Ruch et al. 1973) and summarized in Table VI. More refined analyses of density-graded coal fractions (Zubovic 1975; Gluskoter 1975) indicate that certain elements (barium (B), germanium (Ge), beryllium (Be), titanium (Ti)) tend to concentrate in the lighter or organic phase and others (mercury (Hg), manganese (Mn), chromium (Cr), cadmium (Cd), lead (Pb), zinc (Zn), arsenic (As)) in the heavier or inorganic phase.

The metals contained in the organic part of coal probably occur as chelated complexes (Zubovic 1975). The trace metals in the inorganic portion of the mineral matter probably substitute for metal ions of similar size and valence state in the lattice of the dominant minerals consisting mostly of aluminosilicates, sulfides, sulfates, and carbonates.

In coal, the trace radioactive elements of concern include ^{235}U, ^{238}U, and ^{232}Th and their associated daughter products.

TABLE VI

MEAN ANALYTICAL VALUES FOR 101 COALS

Constituent	Mean	Standard deviation	Min	Max
Arsenic, ppm	14.02	17.70	0.50	93.00
Boron, ppm	102.21	54.65	5.00	224.00
Beryllium, ppm	1.61	0.82	0.20	4.00
Bromine, ppm	15.42	5.92	4.00	52.00
Cadmium, ppm	2.52	7.60	0.10	65.00
Cobalt, ppm	9.57	7.26	1.00	43.00
Chromium, ppm	13.75	7.26	4.00	54.00
Copper, ppm	15.16	8.12	5.00	61.00
Fluorine, ppm	60.94	20.99	25.00	143.00
Gallium, ppm	3.12	1.06	1.10	7.50
Germanium, ppm	6.59	6.71	1.00	43.00
Mercury, ppm	0.20	0.20	0.02	1.60
Manganese, ppm	49.40	40.15	6.00	181.00
Molybdenum, ppm	7.54	5.96	1.00	30.00
Nickel, ppm	21.07	12.35	3.00	80.00
Phosphorus, ppm	71.10	72.81	5.00	400.00
Lead, ppm	34.78	43.69	4.00	218.00
Antimony, ppm	1.26	1.32	0.20	8.90
Selenium, ppm	2.08	1.10	0.45	7.70
Tin, ppm	4.79	6.15	1.00	51.00
Vanadium, ppm	32.71	12.03	11.00	78.00
Zinc, ppm	272.29	694.23	6.00	5,350.00
Zirconium, ppm	72.46	57.78	8.00	133.00
Aluminum, %	1.29	0.45	0.43	3.04
Calcium, %	0.77	0.55	0.05	2.67
Chlorine, %	0.14	0.14	0.01	0.54
Iron, %	1.92	0.79	0.34	4.32
Potassium, %	0.16	0.06	0.02	0.43
Magnesium, %	0.05	0.04	0.01	0.25
Sodium, %	0.05	0.04	0.00	0.20
Silicon, %	2.49	0.80	0.58	6.09
Titanium, %	0.07	0.02	0.02	0.15
Organic sulfur, %	1.41	0.65	0.31	3.09
Pyritic sulfur, %	1.76	0.86	0.06	3.78
Sulfate sulfur, %	0.10	0.19	0.01	1.06
Total sulfur, %	3.27	1.35	0.42	6.47
Sulfur by X-ray fluorescence, %	2.91	1.24	0.54	5.40
Air-dry loss, %	7.70	3.47	1.40	16.70
Moisture, %	9.05	5.05	0.01	20.70
Volatile matter, %	39.70	4.27	18.90	52.70
Fixed carbon, %	48.82	4.95	34.60	65.40
Ash, %	11.44	2.89	2.20	25.80
Btu/lb	12,748.91	464.50	11,562.00	14,362.00
Carbon, %	70.28	3.87	55.23	80.14
Hydrogen, %	4.95	0.31	4.03	5.79
Nitrogen, %	1.30	0.22	0.78	1.84
Oxygen, %	8.68	2.44	4.15	16.03
High-temperature ash, %	11.41	2.95	3.28	25.85
Low-temperature ash, %	15.28	4.04	3.82	31.70

SOURCE: Ruch et al 1973

The concentrations of trace radioactives in coal vary less than those of other trace elements. The national average concentrations of uranium and thorium in coal are 1 ppm and 2 ppm respectively (VanHook 1977).

Major differences exist between the compositions of coal from different mines, and even, in a given mine, between seams. With current interest in greater utilization of Western Coals, it should be noted that these generally have a higher alkali metal content, lower sulfur content, and higher ash content than Eastern coals. Any assessment of health hazards must obviously take into account the wide variation in amount and chemical composition of the mineral matter between coals.

In summary, most of the major environmental pollutants from coals originate as impurities in the coal structure. These include various organic compounds, minerals, inorganic radionuclides, and trace elements that may be released into the air and water when coal is mined, processed, and utilized. These substances can enter the environment either as airborne or waterborne pollutants. In the occupational environment it is the coal dust and associated inorganic dusts that make up the major exposure.

Recommendations

1. In order to ensure that the high levels of control mandated by the Clean Air Act Amendments of 1977 will be attained and maintained, there is need for a vigorous, continued research and development of the pertinent control technologies. Although this report has not focused specifically on control

technologies, it has been assumed that adequate control technologies would be available. The interdependency of control technologies should be recognized in designing measurement programs. For example, staged combustion for NO_x control may result in changes in emissions of carbon monoxide and hydrocarbons, in the formation of submicron inorganic particulates, and in the alteration of the sulfite/sulfate ratio in combustion products with a possible consequence change in the collection efficiency of electrostatic precipitators. Specifically, research is needed on:

- improved flue gas desulfurization (FGD) processes
- improved utilization of acceptor stone (limestone or dolomite) for SO_2 adsorption in fluidized bed combustors
- regenerable processes for both FGD and FBC units
- control of NO_x emissions from conventional, magnetohydrodynamic (MHD), and atmospheric pressure fluidized bed combustors
- understanding of the production of submicron inorganic particulates and the development of methods of reduction of particulates in the respirable size range by both combustion modification and development of improved particulate collectors
- regeneration of potassium sulfate produced in MHD power cycles and disposal of sulfur residue during potassium regeneration
- control of hydrocarbons and CO from small industrial coal-fired combustors.

2. To characterize emissions, assessment of emission indices for the different categories of pollutants and the different processes are required. Certain problems in the characterization of emissions should be recognized. The emissions statistics from conventional technology need to be constantly updated to reflect changes in fuel, in operating conditions, and in control technology. Inasmuch as certain pollutants, e.g., hydrocarbons, are emitted primarily during periods of operation at transient, nondesign, operating conditions, it is imperative that measurements be made over periods that will produce statistically reliable estimations

of emission factors. For processes at the bench- or pilot-scale state of development, it should be recognized that significant changes in emissions may result with scale-up. Another problem in the cost of complete characterization of the organic and inorganic aerosols is such that complete characterization cannot be required on a routine basis. Specific research needs include:

- Characterization of the composition and projected rates of emission from underground coal gasification. Measurement of emissions from coal seams burning out of control might provide interim estimates until data are obtained from field demonstrations.

- Characterization of the emissions of total hydrocarbons from coal combustors of different design and scale. Measurement programs should be designed to recognize the role of upsets or deviations in the operating conditions on emissions and the higher potential emissions from small-scale industrial combustors.

- Extensive characterization of the organic emissions by chemical type and distribution between gas phase, condensation products, and adsorbed phases on ash and soot should be carried out for selected cases. The distribution of the condensed and adsorbed species between different size fractions needs to be determined. The detailed information should be used to (i) narrow down the compounds and size fractions that need to be measured on a routine basis (ii) determine indicator compounds, e.g., methylated polynuclear aromatics, which may be used to distinguish coal-derived organics from those from other combustion sources in ambient aerosols.

- Measurement of emissions of inorganic particulates from coal utilization facilities in the respirable size range having potential human health effects.

- Detailed characterization of the combustion-generated, inorganic aerosols to provide guidance to potential health effects. The detailed characterization preferably should be focused on those aerosols in the smaller size/surface area ranges. For toxic trace metals, the chemical and valence state of cation and anion, crystallinity, and physical form of the particulate should be determined. The difference in combustion temperature and history of particles produced in fluidized bed combustors, stokers, conventional pulverized, and MHD combustors should be noted in the design of the measurement program. The data should be used to identify the need to provide, on a routine basis, detailed characterization of the aerosols produced by combustors.

- The possibility for adverse synergistic effects of cocombustion of coal with oil or refuse-derived fuels should be examined. Three possible effects are (a) the catalytic conversion of coal-generated SO_2 to SO_3 by vanadium in fuel oil; (b) increased vaporization of the trace metals in refuse-derived fuels due to exposure to higher temperature when cocombusted with coal than those encountered in incinerators, and (c) the impact of the chlorine in refuse-derived fuels on the composition of coal combustion products.

- The rates of leaching from storage piles of ash and solid wastes should be monitored for different methods of impoundment. Because of the dependence of the physical state of ash and waste on combustion conditions, measurement of the leaching potential of ashes produced by different conventional and advanced technologies is needed.

3.0 EVALUATION OF EXPOSURE TO COAL-DERIVED POLLUTANTS

The health and environmental effects resulting from the expansion of existing coal utilization technologies and from the introduction of new technologies, will be dependent upon the physical and chemical characteristics of the effluents and on their source strengths and distribution patterns in space and time. Effects on health will also be influenced by the amounts of time that the individuals are exposed to the various effluents, their levels of activity while exposed, and their individual susceptibilities to the various biological effects. It is usually difficult to characterize the biological responses to exposures to the various coal utilization technologies' effluents because they involve complex mixtures of widely different materials. The effects produced may also not be specific to one kind of exposure and may have a background incidence.

Quantitative evaluations of exposure are important in any characterization of health or environmental effects. Where dose-response relationships are already established and environmental standards exist, measurements of exposure provide a basis for decision making concerning control effectiveness and performance. Where causal relationships are known or suspected, but quantitative exposure standards have not been established, the detection of contamination levels higher than background indicates that greater attention to the control of emission sources is warranted. In such cases, it is also desirable to keep a close watch on both levels of exposure and health

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indices in the exposed populations in order to establish dose-response relationships which can be used to provide a basis for better controls in future operations and to stimulate the development of more sensitive indices of exposure and effects.

Research needs concerning exposure evaluations can be identified in several specific areas including sampling strategies, sampling techniques, equipment development, and techniques for physical and chemical separations and analyses. Within these general topics, the needs will vary depending on the receptors of interest, i.e., occupationally exposed populations, populations exposed to effluent streams from the plant, and environmental receptors (vegetation, livestock, aquatic life, etc.).

Further breakdown is needed by coal utilization technology, since the technologies are so diverse. On the other hand, there are some generic elements involved, and these will be discussed first in order to minimize the necessity for repetitive discussions under each individual utilization technology.

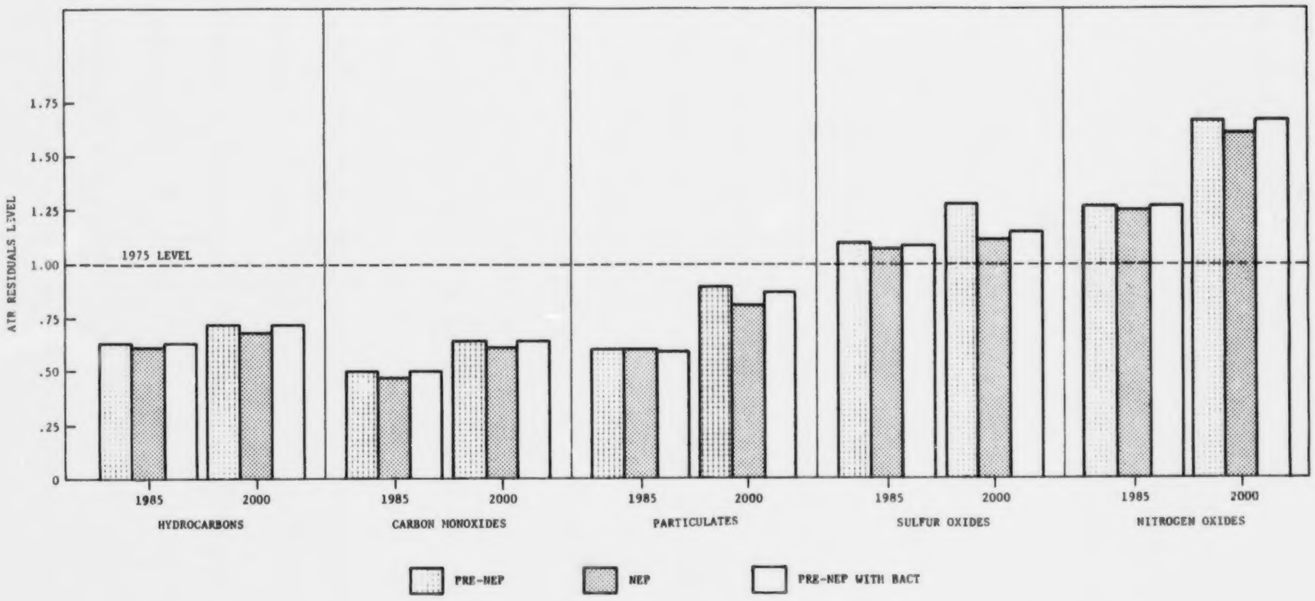
3.1 Generic Exposure Considerations

Among the process steps common to almost all of the technologies are coal mining, transport, and comminution (size-reduction). In all of these, there is a significant amount of dust generation and release and it may be necessary to perform physical and chemical characterization of the dusts and their temporal and spatial distributions by concentration and size distribution.

Similarly, coal combustion is a process common to many of the technologies under consideration. The amounts and compositions of the combustion effluents will depend on the temperatures and residence times in the combustion zones. Even with relatively complete combustion, there will still be significant amounts of sulfur oxides, nitrogen oxides, mineral ash, and volatile metals. With less complete combustion, there will also be a large number of organics, including pyrolysis products and the products of pyrosynthesis within the fuel-rich flame. Such mixtures may be expected to include carbon monoxide (CO), polynuclear aromatics (PNAs), aldehydes, ketones, and epoxides.

In situ coal gasification represents a special case, as the combustion occurs at a lower temperature underground and is intentionally oxygen deficient. The mixture of products of the partial combustion which occurs will therefore be very different from those in the other processes and will include much higher proportions of aromatics and oxidized hydrocarbons as well as substantial amounts of hydrogen sulfide (H_2S), carbonyl sulfide (COS), mercaptans, and thiols (Braunstein et al. 1977). Such potent mixtures are, of course, expected to be collected and processed at an above ground plant and not released to the environment. Some releases are, however, inevitable through vents in the underground rock strata which cannot be controlled.

In order to develop a perspective on the extent of community exposures to pollutants generated by the coal utilization technologies, it is necessary to consider the best available projections on total coal usage, the anticipated applications of the available coal utilization technologies, and the collection efficiencies of the best available control technologies. In terms of air pollution by the so-called criteria pollutants, projections by MITRE (1977) of emissions of SO_x, NO_x, and particulates for 1985 and 2000 are shown in Figure 5. Included are scenarios of projected coal utilization for pre-National Energy Plan (NEP) with business as usual for NEP and for pre-NEP with best available control technology (BACT) corresponding to 81 percent scrubber efficiency for SO_2, 0.05 lbs/10^6 Btu for particulates, and 0.7 lbs/10^6 Btu for NO_x. These projections suggest that the major impact of increased coal utilization through 2000 will be a moderate increase in SO_x emissions and a significant increase in NO_x emissions. The problems anticipated from increased coal utilization are localized, generally occurring in the industrialized areas where ambient levels of pollutants are high or in the South and West where the increase in coal utilization will be large. A major shift is expected to occur in the fractions of the total coal mined and used west of the Mississippi. It is projected that in the period 1975 to 2000, the fraction of the coal mined in the Western states will increase from 0.14 to 0.44 and the fraction of coal used



Source: MITRE 1977

FIGURE 5
AIR RESIDUALS LEVELS FOR 1985, 2000 RELATIVE TO 1975

in industrial and utility boilers west of the Mississippi will increase from 0.11 to 0.38 (MITRE 1977). These data do not reflect production changes related to the energy Security Act of 1980.

Problems associated with the development of control technologies for the major pollutants can be identified.

3.1.1 SO_x

The projected moderate increases in total emissions of SO_x are based on the assumption that the high levels of control mandated by the Clean Air Act Amendments of 1977 will be attained and maintained. Further research and development efforts in control technology to meet the intent of BACT is needed. In addition, it is necessary to improve the efficiency and reduce the cost of regenerable flue gas desulfurization processes in order to eliminate the problems associated with sludge disposal. A different set of disposal problems from those encountered with sludges from flue-gas desulfurization processes is expected for fluidized bed combustors as a consequence of the high alkali content of the solid waste produced.

Sulfur capture in fluidized bed combustors is achieved by the introduction of a sorbent, usually limestone or dolomite, into the fluidized bed. The amounts of sorbent required to attain high sulfur capture efficiencies are usually in excess of twice the stoichiometric amount, with a consequent aggravation of the solid disposal problem. Regenerable processes are under investigation and offer a potential longer range solution to the disposal problem.

For MHD power plants, a high efficiency of sulfur capture is achieved by the nearly quantitative capture of the sulfur oxides by the potassium carbonate seed. The possible emissions from the seed reprocessing plant are potential problems.

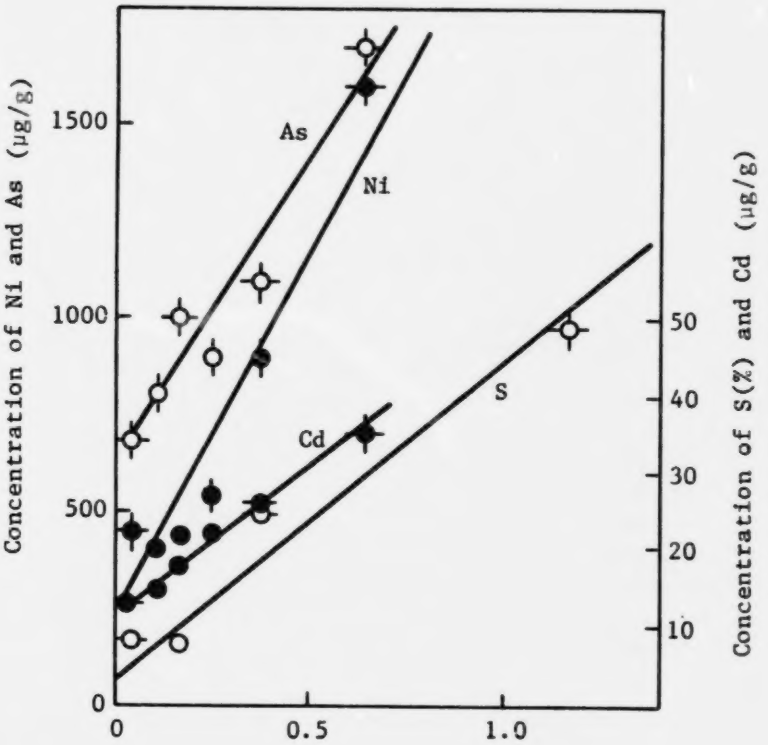
3.1.2 Particulates

It is recognized that regulation of total particulate emissions does not address the particulates of concern to human health, and that the emission of particulates in the respirable size range may be increasing if the decrease in total emissions is achieved by the preferential reduction in emissions of larger particles which account for most of the mass of emissions. Additional effort is needed in the development of control technologies for fine particulates and in developing a reliable method for monitoring the particles in the size range of concern.

The role of particulates in promoting adverse health effects is not clear. Detailed characterization of the chemical and physical form of particulates emitted by coal combustors is needed for purposes of a rational evaluation of potential health effects. Significant progress has been made recently in characterizing the fine particulates from pulverized coal combustion. Certain trace elements are found to concentrate preferentially in the smaller size fractions of flyash (Davidson et al. 1974; Kaakinen et al. 1973; Klein et al. 1975; Keyser et al. 1978; Natusch et al. 1974; Coles et al. 1979) with an increase in concentration in proportion to the reciprocal of the particle diameter (Figure 6). This is a consequence of the vaporization and recondensation of volatile species.

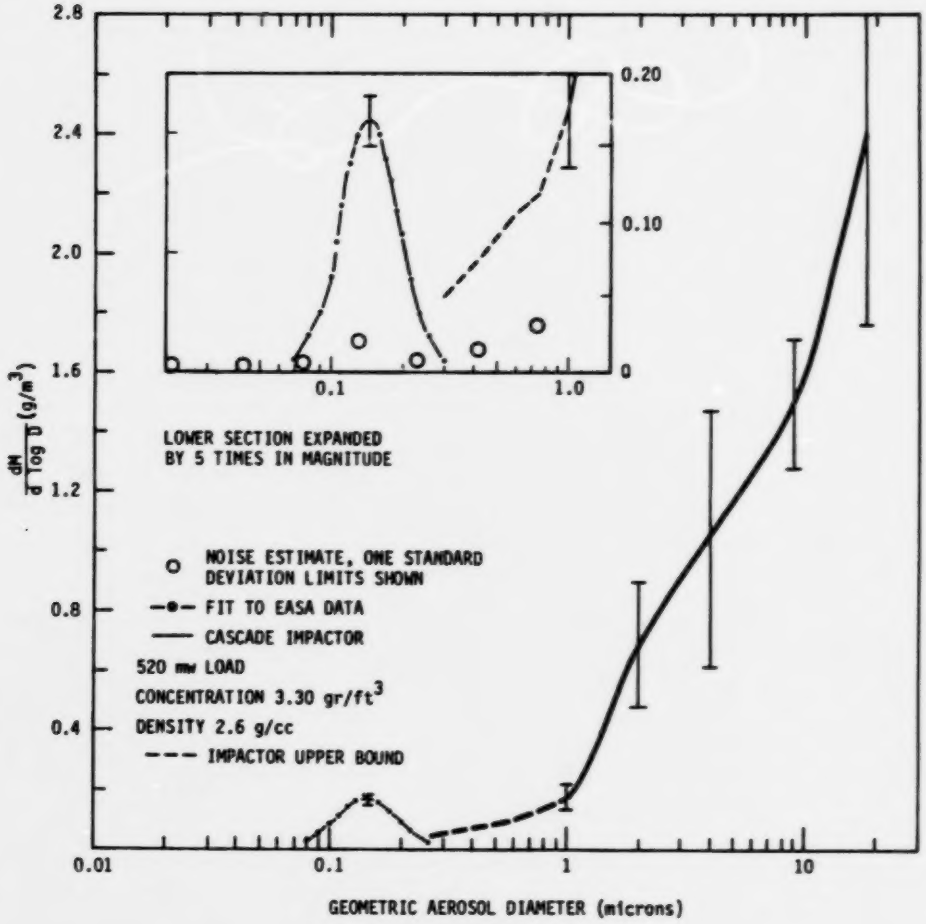
As would be expected, the surface layers of the flyash are greatly enriched in the concentration of the volatile species. Selected ratios of surface to bulk concentrations measured by ion microprobe mass spectrometry (Linton et al. 1976) are 10 (Te), 11 (Pb), 7.2 (Zn), 6.0 (Be), 313 (Cr), 7.6 (K), 15.2 (Na), and 7.7 (S). These concentration ratios were considered to be minimum values because of background interference in their mass spectral analysis and correction of the background for Pb and Te increased the estimates of surface to bulk concentration to 30 and 50, respectively. These studies underline the fact that, because of preferential concentration of volatile species on the surfaces of the smaller particles, bulk concentrations of elements in flyash are a poor indication of potential health effects.

An additional finding is that constituents of the combustion vapors nucleate homogeneously to form submicron particles. This results in a bimodal distribution of the ash particles produced as a function of size. Illustrations of the size distribution before and after electrostatic precipitation at a 520 MW coal-fired utility boiler are shown in Figures 7 and 8 (Ensor et al. 1979). The particles produced by the condensation of vaporized species show a peak in diameter between 0.1 and 0.2 μm. It is evident from a comparison of Figures 7 and 8 that the collection efficiency for these particles is low in relation to the larger particles. It is



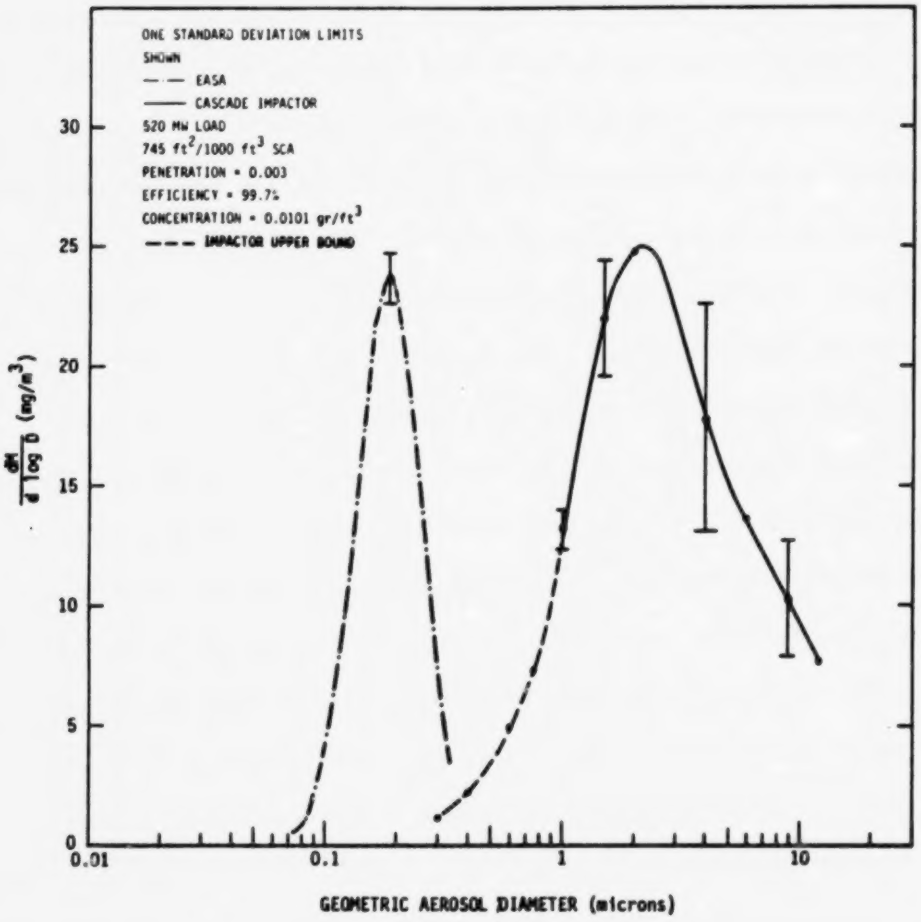
Source: Natusch et al 1974

FIGURE 6
DEPENDENCE OF THE AVERAGE CONCENTRATIONS OF AS, NI, CD, AND S ON AIRBORNE PARTICLE SIZE IN COAL FLY ASH



Source: Ensor et al. 1979

FIGURE 7
DIFFERENTIAL MASS PARTICLE SIZE DISTRIBUTION
AT THE INLET OF THE ELECTROSTATIC PRECIPITATOR



Source: Ensor et al. 1979

FIGURE 8
DIFFERENTIAL MASS PARTICLE SIZE DISTRIBUTION AT THE OUTLET OF THE ELECTROSTATIC PRECIPITATOR

important that the processes governing the production of these submicron particles be understood in order to design air pollution control devices that will meet the high performance requirements of the New Source Performance Standards (NSPS) under the Clean Air Act.

Although progress has been made concerning the characterization of the elemental composition and size distribution of aerosols emitted by coal combustors, little is known about the chemical form, of both cations and anions, or crystallinity of the particles emitted. Routine, complete characterization of the particulate emissions is unrealistic. The nature of the flyash from stokers, fluidized bed combustors, and MHD plants will reflect the very different temperatures to which the ash has been subjected. The temperatures in fluidized bed combustors are, by design, below the ash fusion temperature. The flyash from FBCs is therefore loosely sintered, friable, and irregular in shape (Carpenter et al. 1978) in contrast to the predominance of fused glassy spheres in the ash produced in pulverized coal flames (see Fisher et al. 1977 for morphological characterization of ash from conventional utility boilers). The smaller size fractions of the flyash from fluidized beds are also enriched in volatile trace elements, but the enrichment factor appears smaller than that reported for pulverized coal flames.

The temperature of operation of MHD combustors is high enough to ensure fusion and extensive vaporization of the ash. The ash carry-over will depend upon the design of a plant. The flyash from MHD units is expected to consist of glassy spherical particles, or condensed products with a smaller particle size and higher trace element concentration. These particulates will also be more alkaline than those from conventional pulverized coal boilers.

3.1.3 NO_x

The NO_x emissions from coal-fired plants are generally higher than those from gas- and oil-fired power plants because of the contribution to emissions by the nitrogen organically bound in the coal. Without development of improved control technologies, the emissions of NO_x would increase substantially with increased coal utilization. Therefore, a need exists for continual research and development of strategies for reducing the NO_x from coal. Modification of the combustion process shows promise for achieving levels of emissions from coal comparable to those currently attainable with oil (Martin 1979), but care must be taken that the changes in the combustion process do not alter the emissions of other pollutants. Preliminary studies of the impact of NO_x control strategies on the emissions of other pollutants show little effect on SO_x and particulates and a slight increase in concentrations of organics (Waterland et al. 1979).

The bulk of the emission data from pilot units for expected operating temperatures of fluidized bed combustors (1090 to 1150°K) lie between 0.3 and 0.6 lb $NO_x/10^5$ Btu, which is less than the current NSPS (Henschel 1977). Pressurized fluidized beds show considerably lower emission levels, on the order of 0.2-0.3 lbs/10^6 Btu (Hoy and Roberts 1972).

High concentrations of NO_x are produced in the combustion chamber of open-cycle MHD power plants. Strategies for reducing the NO_x emissions by fuel rich operation of the combustor and completion of the combustion after cooling the combustion products at a controlled rate downstream of the MHD channel have been developed (Bienstock and Maslennikov 1978). Verification of the control strategies on pilot and demonstration units is needed.

3.1.4 CO and Hydrocarbons

Total emissions of CO and hydrocarbons are expected to decrease, largely because of the reduction of the contribution from mobile sources. The major potential for emissions of CO and hydrocarbons from coal combustors will be from the smaller units utilized by the industrial sectors. The major issue needing resolution is the characterization of the composition and amounts of the organic constituents.

3.1.5 Polycyclic Organic Matter

Polycyclic organic matter (POM) is an indication of incomplete combustion and is present in highest concentrations in the products from poorly controlled combustion systems such as coal refuse burning, hand-stoked residential coal-furnaces, and systems starved of air such as coke ovens. The large number of compounds present in polycyclic organic matter, their complex distribution between the particulate and gas phases, their low concentrations, and their reactivities all contribute to the difficulty of collecting and measuring their concentrations in combustor effluents. The data base is very sparse and makes evaluation of national emission inventories difficult. Measurements made on a small sample of coal-fired combustors in the 1960s (Cuffe et al. 1964; Faoro 1975; Gerstle et al. 1965; Hangebrauck et al. 1964; and Hangebrauck et al. 1967) represented the only available data during the 1970s. They were used by the National Academy of Sciences to provide the estimates in Table VII of the emissions of benzo(a)pyrene from major sources in the U.S. Although the estimates are highly questionable, they underline the fact that it is the poorly controlled combustors which dominate the emissions of POM. They also suggest that the major sources of POM from the use of coal are refuse piles, coke production, and hand-stoked furnaces if coal should again become a significant fuel for residential heating.

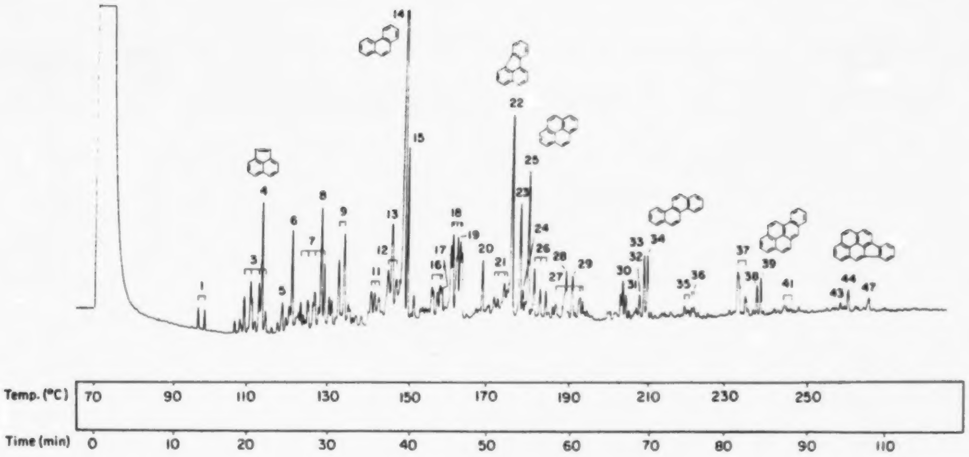
The major contributors to POM in the atmosphere need to be reassessed for the changing mix of combustion sources with more detailed chemical and physical characterization of the POM. Detailed characterization of the POM from coal burning plants (Griest 1979; Natusch and Tomkins 1977) shows side chain substituted POM in addition to the major POM peaks observed in the products of combustion of petroleum (see Figure 9). The side chain substituents may serve as tracers for POM generated by coal sources. Heterocyclic POMs

TABLE VII

ESTIMATES OF NATIONAL EMISSIONS OF BENZO[A]PYRENE

CLASSIFICATION	SOURCE		ESTIMATE [tons/year]
		SUB-CATEGORY	
Vehicular			22
Heat and Power Generation	Coal	Hand-stoked furnaces	420
		Stokers	10
		Power-plants	1
	Oil		2
	Gas		2
	Wood		40
Industrial	Petroleum		6
	Asphalt air-blowing		<1
	Coke production		200
Refuse-burning	Enclosed incinerator:		
	Municipal		4
	Commercial		10
	Domestic		10
	Forest & Agricultural		140
	Vehicle disposal		50
	Coal refuse piles		340

Source: NAS 1974.



PAH identified by g.c.m.s.

Peak No.	Compound	Peak No.	Compound	Peak No.	Compound
1	Methylnaphthalene	17	Propyldibenzofuran[b]	33	Benz[*a*]anthracene
2	Biphenyl	18	Methylphenanthrene[c]	34	Chrysene
3	Ethylnaphthalene[a]	19	4*H*-cyclopenta[*def*]phenanthrene	35	Methylchrysene[e]
4	Acenaphthylene	20	Methyl-4*H*-cyclopenta[*def*]phenanthrene	36	Methylcyclopenta[*cd*]pyrene[f]
5	Methylbiphenyl	21	Ethylphenanthrene[a]	37	Benzofluoranthene
6	Dibenzofuran	22	Fluoranthene	38	Benzo[*e*]pyrene
7	Propylnaphthalene[b]	23	Benz[*e*]acenaphthylene	39	Benzo[*a*]pyrene
8	Fluorene	24	Benzo[*def*]dibenzothiophene	40	Perylene
9	Methyldibenzofuran	25	Pyrene	41	Methylbenzopyrene[g]
10	$C_{14}H_8$[h]	26	Ethyl-4*H*-cyclopenta[*def*]phenanthrene[a]	42	$C_{21}H_{12}$ (unknown)
11	Methylfluorene	27	Methylfluoranthene[d]	43	$C_{21}H_{12}$ (unknown)
12	Ethyldibenzofuran[a]	28	Benzo[*a*]fluorene	44	Indeno[1,2,3-*cd*]pyrene
13	Dibenzothiophene	29	Benzo[*b*]fluorene	45	Dibenz[*a,h*]anthracene
14	Phenanthrene	30	Benzo[*ghi*]fluoranthene	46	Dibenz[*a,c*]anthracene
15	Anthracene	31	$C_{18}H_{10}$ (unknown)	47	Benzo[*ghi*]perylene
16	Ethylfluorene[a]	32	Cyclopenta[*cd*]pyrene	48	Anthanthrene

[a] Could be dimethyl.
[b] Could be trimethyl or ethylmethyl.
[c] Could be methylanthracene.
[d] Could be methylpyrene.
[e] Could be methylbenz[*a*]anthracene.
[f] Could be methylbenzo[*ghi*]fluoranthene.
[g] Could be methylbenzofluoranthene.
[h] Probably cyclopent[*bc* or *fg*]acenaphthylene.

Figure 9

Chromatograms of Extracts of Coal and Kerosens Soots

SOURCE: Lee et al 1977

TABLE VIII

ESTIMATED PAH CONCENTRATIONS IN ESP HOPPER ASH

Peak No.	Tentative Identification	Concentration in Ash, ng/g
5	Phenanthrene	0.5
10	2-Methyl Phenanthrene	0.1
12	C_1-Phenanthrene	<0.05
13	1-Methyl Phenanthrene	0.06
16	2-Phenyl Naphthalene	0.1
19	C_2-Phenanthrene	0.02
22	C_2-Phenanthrene	0.06
23	C_2-Phenanthrene	0.05
24	Fluoranthene	0.4
26	Pyrene	0.1
27	m-Terphenyl	0.8
28	p-Terphenyl	0.9
29	Benzo(a)fluorene	0.2
32	Benz(a)anthracene	0.05
33	Chrysene/Triphenylene	0.2
34	Benzo(e)pyrene	0.1
35	Benzo(a)pyrene	0.03
36	Benzo(ghi)perylene	0.03
	TOTAL	3.75 ng/g

Source: Griest et al. 1979.

containing N and S are expected in coal combustion products, but their concentrations have not yet been reported.

POMs have been measured in extracts of flyash recovered from a hopper of electrostatic precipitator (Table VIII). Data are needed on the distribution of POMs in stack emissions for those in vapor phase and those adsorbed on different particle fractions.

The cost of detailed characterization of the POMs precludes routine analysis of stack samples. It is likely that large continuous combustors are minor sources of POMs relative to combustors that operate intermittently.

3.2 Measurement of Exposure

The adequacy of existing technology for measurement of exposure varies considerably with the processes and pollutants of concern, as well as with the sensitivity required. In some cases, an analytical technique may be adequate for occupational exposure assessments, but inadequate for community air quality evaluations where the permissible concentrations are much lower. In the workplace, the influence of other air contaminants on the analyses may be negligible or subject to correction by suitable calibrations. In community air, however, there may be many more co-contaminants which can influence the results and the mixtures may be too complex for the application of calibration factors.

In general, there are many more measurement options for gases and vapors than for aerosols, especially with regard to direct reading instruments and personal alarms and exposure monitors.

Direct reading instrumentation for aerosols is limited to measurements of particle number or mass concentrations. Determination of the concentrations of specific chemical species in the aerosol generally requires the extraction of the particles from the air onto a collection surface over a specified sampling interval. The time delay between sample collection and determination of concentration is limited by the time required to perform the chemical separations and analyses.

The situation is particularly complex for aerosols arising from the handling, processing, and combustion of coal. In many of these operations, the number of individual chemicals associated with the aerosol is so great that a complete analysis is not feasible either technically or economically. If the chemical species in these mixtures having the greatest potential impacts on inhalation hazards or environmental quality were established, then the modern analyst could develop the analytic procedures to identify and quantify them. Unfortunately, the extent of the hazard associated with many of the materials present in these mixtures is not known when they are present alone or in representative mixtures.

3.2.1 Occupational Exposure Measurements

The primary purpose of workplace monitoring is to evaluate exposures so that controls can be instituted to protect the health of the worker. Examples of additional ways in which occupational and environmental monitoring can be used in coal utilization facilities include:

- monitoring the performance of engineering controls
- developing design requirements for new engineering controls
- documenting exposure levels
- testing for compliance purposes
- measuring process losses to the environment
- selecting suitable respiratory protection devices
- identifying contamination sources
- assessing emergency conditions

The instrumentation required is often a function of the purpose of the exposure evaluation. An in-depth evaluation of instrumentation requirements should address conditions that are:

- high risk, immediately hazardous
- high risk, but not immediately hazardous or
- moderate risk and not immediately hazardous.

For each of these conditions, the following questions must be answered before a priority can be affixed:

- What compounds are represented in this class?
- Is monitoring technology available for present needs?
- Is current technology compatible with future needs?
- If not, is technology being developed to meet the projected needs?
- When will the technology be needed?
- When will that technology be available?

The increased emphasis on occupational safety and health initiated by legislative action in the early 1970s has resulted in some significant gains in the development of monitoring tools for occupational health surveillance. Requirements for more precise and accurate evaluation of workplace exposures have led to the production of noise dosimeters, passive dosimeters for certain gases and vapors, portable real-time monitors for organic vapors, low flow rate pumps, more sensitive and accurate detector tubes, more specific analytical methods, heat stress monitors, and direct-reading dust monitors. These improvements in monitoring technology have simplified the task of those involved in monitoring employee exposures. Unfortunately, most advances have been made in areas where traditional monitoring techniques already existed rather than in areas recently identified as potential health hazards. The emerging coal utilization industries represent such an area since the base materials may contain most of the elements found in the periodic table and the processes and conditions used can result in synthesis of a host of highly toxic by-product chemicals.

A review of current industrial hygiene monitoring technology indicates that there are adequate tools for monitoring traditional contaminants--silica dust, carbon monoxide, oxides of nitrogen, coal dust, hydrogen sulfide, and sulfur oxides. However, some contaminants which pose a high potential long-term risk (e.g., organometallic compounds) are not being monitored to the extent desirable because of lack of technology, high costs, long analytical procedures, lack of specificity, inadequate sampling, and/or inefficient recovery procedures. Although current occupational health monitoring is locked into using technology and tools that are presently available, future assessments of occupational health problems in commercial coal utilization plants will require additional, more sophisticated tools.

Recommendations

1. Additional evaluation of current instrumentation under various conditions and interferences, temperatures, pressures, humidity, and related variables is needed to ascertain their appropriateness for future needs.
2. Research on aerosol concentration measurements should be focused primarily on:
    - improving extraction efficiency and separation techniques for organic components absorbed or adsorbed by particulates
    - specifying chemicals as a function of particle size instead of by structure for organic compounds and by anions and cations for inorganic compounds
    - separating benzene soluble and insoluble particulates during sampling.
3. Research is needed to develop monitoring methods for organometallics which are potential hazards in fossil fuel conversion and coal cleaning processes. These include compounds containing arsenic, beryllium, cadmium, chromium, or nickel.
4. Instrumentation which can measure the contamination of the skin of workers in coal processing industries should be developed.
5. Procedures are needed to identify human body burdens resulting from several routes of exposure.

3.2.1.1 High Risk, Immediate Hazards. Six compounds have been identified which are present in sufficient quantities that acute exposure could occur with associated immediate and serious impairment to life and health. These include:

- H_2S - acute poison (respiratory failure)
- CO - acute chemical asphyxiant
- NO_x -NO_2 - delayed pulmonary edema
- O_2 deficiency
- coal and shale dust - explosion hazard
- H_2 - explosion hazard.

The working group believes that technology is available to provide equipment which can be used as personal and area monitors with continuous direct reading and/or alarm capabilities for H_2S, CO, O_2, and H_2. Technology is presently lacking, however, for monitoring explosive levels of coal dust and for NO_x-NO_2 personal alarming devices. Future needs may require personal monitors capable of transmitting a signal to bring outside assistance in emergencies. Phenols, hydrogen cyanide, metal carbonyls, and carbon disulfide should also be included in this category if concentrations in the workplace are potentially high. This may occur in connection with in situ coal gasification.

In most cases, exposure to life-threatening concentrations should occur only as the result of a leak. Rather than relying on individual monitoring of several hazardous materials, a single indicator might be monitored to give warning of a leak under otherwise normal operating conditions. In gasification plants where the process stream includes high concentrations of CO, this gas has been suggested as an indicator. However, in other situations CO may not be the best choice. The indicator must be present in sufficient concentration to give warning in all process streams carrying immediately hazardous substances. For each type of plant it will be necessary to determine the indicators appropriate for leak detection for each work area. Fixed alarm monitors are most appropriate together with survey meters.

Recommendations

1. Instrumentation is needed to measure airborne concentrations of coal dust in the explosive concentration range and peak NO_2 levels using a personal monitor alarm.
2. For immediately hazardous exposures, development is needed of new sampling instruments which will facilitate automated analysis and data recording to permit handling large amounts of data generated during routine monitoring, e.g., operational personal gas chromatography units capable of multiple compound analysis, miniaturization of existing devices, continued phototype development, and simplified analytical procedures.

3.2.1.2 High Risk, But Not Immediately Hazardous. Substances which may cause irreversible effects to body organs or systems but which are not present in sufficient quantities to produce acute toxicological effects include those compounds which are carcinogenic, mutagenic, teratogenic and affect reproduction, as well as trace metals, silica dust, and asbestos fibers. There is the potential for exposure to so many of these substances that the working group believes it to be impracticable to monitor them routinely except when dictated by regulatory requirements. The evaluation of one or more indicator compounds is a logical approach.

Some investigators have adopted or suggested benzo(a)pyrene (BaP) as an indicator chemical for the polynuclear aromatic hydrocarbons on the basis that it is likely to be present in most mixtures, it is a known and potent animal carcinogen, and it can be routinely analyzed by techniques of proven reliability. While it is likely to be present to some degree in most mixtures, its contribution by mass or biological activity is likely to be highly variable.

An epidemiological study of roofers exposed to very high concentrations of BaP found some excess lung cancer among those exposed for more than 20 years (Hammond et al. 1976). The Standard Mortality Radios (SMRs) for those exposed for 9-19, 20-29, 30-39, and $\geq$ 40 years were 92, 152, 150 and 247 respectively (the smoking histories of the workers, however, were not known). Airborne BaP concentrations measured in roofing operations range from 14 μg/m3 in the roof-tarring area, to 6,000 μg/m3 in the vicinity of the coal-tar roofing kettle (Sawicki 1967). The amounts of BaP recovered from masks, which were worn by a minority of roofers studied, indicated an average of 16.7 μg BaP inhaled per day (Hammond et al. 1976). Another group exposed to high concentrations of airborne BaP were British gasworkers, who inhaled about 30 μg/day (Lawther et al. 1965).

In 1960, the mainstream smoke of a cigarette was shown to contain 3.5 x 10-2 μg of BaP, (Kotin and Falk 1960) although the levels are lower now. Thus a 2 pack/day smoker inhaled 1.4 μg/day. Ambient urban air in 1958 contained about 6 ng/m3, (Sawicki 1967) which could account for an inhaled mass of 120 ng/day, i.e., 0.12 μg/day. Rural ambient air has about 10 percent as much BaP.

The lung cancer SMRs for rural nonsmokers, urban nonsmokers, light smokers ($\leq$ 1 pack/day), heavy smokers (> 1 pack/day), roofers (20 years exposure, and including many smokers) and gasworkers (including smokers) are 14, 16, 124, 502 (Haenszel et al. 1962), 159 (Hammond et al. 1976) and 169 (Doll et al. 1965), while their daily BaP exposures are of the order of 0.012, 0.12, 0.70, 0.7 to 2.5, 17, and 30 μg respectively. Clearly, BaP exposures are not particularly good indicators of lung cancer risks.

All of the exposures cited involve a mixture of organic compounds and other toxicants as well, but the influences of each, and their interactions, cannot be determined. Since no single indicator may be adequate, and different indicators may be needed in different situations, further research is needed to study unit operations and process streams from both the chemical and biological standpoints and to identify indicators that are representative of the biological effect from the expected exposure. The strategy recommended is to identify a variety of potential indicators (e.g. one-half dozen), the place where each is likely to be useful, and the kind of monitoring required. In general, personal or survey instruments will be appropriate. The state-of-the-art for monitoring each compound by the methods needed should be assessed and finally, if necessary, new instruments should be developed. Since the final selection and evaluation of specific indicators cannot be made until a commercial plant is built, it is necessary to have available at that time a number of indicators to choose from for which instrumentation is available. Since this instrumentation will probably be group selective, a common line of development will lead to instruments capable of measuring several indicator compounds.

Recommendations

1. Research is needed to identify indicator compounds or groups of compounds which can serve as surrogates for complex mixtures of organics in order to permit development of realistic hazard indices for inhalation exposures. The ultimate objective is to be able to measure the indicator compounds with survey instruments and/or personal exposure monitors that are light in weight and reasonable in cost.

2. Further research is needed to identify direct biological indicators of hazard (such as the Ames *Salmonella typhimurium* test and the *Tradescantia* test system). There is a need to refine protocols and to develop standard biological test systems. These test systems must be compared with chemical indicators; they have the potential of being used as one means of evaluating chemical indicators.

3. Portable survey instruments should be developed and available for evaluating hazards to health during emergencies involving high risk, but not immediately hazardous compounds.

4. Personal samplers that either internally record the results of real-time analysis over the course of the day or collect an integrated sample over a day need to be developed for high risk, but not immediately hazardous chemicals. The latter sampler could be inserted into a device at the end of the day which analyzes and records the exposure automatically with precision and reproducibility.

3.2.1.3 *Moderate Risk, But Not Immediately Hazardous*. The working group anticipates increasing demands to provide a comprehensive record of all hazardous compounds to which a worker is exposed which will require increased use of personal monitors, automated chemical analysis, and computerized data-handling systems. The appropriateness of using area monitors to assess potential health hazards of individual workers should be evaluated. Contaminant releases are likely to be localized suggesting possible limited use of area monitors to measure exposures to individuals.

Recommendations

1. Currently available personal monitors for gases require additional evaluation under various conditions of interferences, temperatures, pressures, humidity, and related variables to ascertain their appropriateness for future needs.
2. It is likely that passive monitors will remain a primary monitoring tool. Improvements needed include development of new substrates to expand the diversity of measurable compounds and to allow for higher sampling flow rates. This area of investigation is likely to provide high payoffs within a few years.
3. Current personal sampling pump flow rates need to be improved to provide higher collection capabilities (5 to 10 lpm) for particulates and for biological test system samples (e.g., Ames test).
4. The working group encourages the development of new sampling instruments which will facilitate automated analysis and data recording to permit handling large amounts of data generated during routine monitoring, e.g., personal gas chromatography units capable of multiple compound analysis, miniaturization of existing devices and simplified analytical procedures.

3.2.2 Environmental Exposure

The adequacy of measurement techniques for environmental exposure evaluations can only be defined in terms of specific contaminants. Thus, in order to define methodology problems in the measurement of exposures to effluents and emissions of coal utilization technologies, it is necessary to define which contaminants are likely to be encountered in concentrations sufficient to produce effects. For well-developed technologies, the exposures of concern have been characterized and techniques for their evaluation have, for the most part, been established.

The major problems in exposure evaluations for coal utilization technologies are associated with the developing technologies. One difficulty lies in defining the compositions and concentrations of the effluents and emissions. Complex mixtures of organics exist at various points along the process streams. Furthermore, the stream compositions vary greatly from process to process, as functions of the compositions of the starting materials and the operating parameters in each process. The exposures of downwind populations will depend on the design and performance of the effluent recovery systems and the extent of fugitive emissions. Unfortunately, for the developing technologies, the only data currently available on effluent releases are from pilot-scale operations, and there are very few of these. In any case, the results have limited predictive value for full-scale plants because of likely variations in operating factors, and because the effluents acceptable in a pilot-scale operation may be unacceptable in a full-scale plant. Thus, the controls specified on the basis of the pilot-plant or demonstration plant experience may not be sufficient to prevent the release of hazardous effluents into the community environment of the full-scale plant.

While the exact compositions of the process and waste streams from coal utilization technologies will be highly variable, it is clear that many of them will contain large numbers of hydrocarbons that may be mutagens, teratogens, reproductive hazards, carcinogens, cocarcinogens, initiators, and tumor promoters. Short term screening tests for biological activity coupled with chemical analysis can give an indication of the carcinogenic/mutagenic activity of the mixture. This seems to be the most logical approach to determining the activity of mixtures.

Exposures to fuel cycle pollutants can take place via several different pathways, i.e., inhalation, skin absorption or penetration, and ingestion. There can also be exposures to excessive levels of physical agents including noise, ionizing radiations (x and γ radiation, short λUV) and nonionizing radiations (long λUV, visible light, IR, microwaves). Measurements of the concentrations of chemicals in the air, drinking water, and food can frequently be supplemented by measurements which determine toxicant accumulations or effects, e.g., measurements of in vivo burdens, concentrations in body fluids or tissues, and concentrations in excreta such as urine, feces, hair, and exhaled air.

Airborne effluents which are inhaled can cause deleterious effects on the respiratory tract or can affect more distant organs if taken up systemically via the airways or gastrointestinal tract. They can also reach human receptors via more indirect routes, i.e., via deposition on vegetation, soil, or surface waters and incorporation into life forms participating in food chains of relevance to human diet. Along these routes, the contaminants may undergo biotransformations and/or biomagnifications of concentration which may enhance their potential for adverse effects.

Liquid and solid effluents of the coal utilization technologies may also contribute to human uptake of toxicants via aqueous leaching of the wastes from mines, storage piles, and waste burial sites. Draining of such wastes into streams and/or groundwater which serve as sources of irrigation or drinking water can provide a pathway to human ingestion.

Current community air monitoring technology is highly developed for some of the chemical contaminants of interest, yet grossly inadequate for others. There are quite adequate continuous monitors for CO, SO_2, NO_2, O_3, and nonmethane hydrocarbon vapors, and they can provide accurate and reliable indications of both peak and time-averaged concentration levels.

Sensitive analytical techniques appropriate for determining the contents of tissues, excreta, and air and water samples are generally available, although research and development of techniques for concentrating and/or separating the contaminant from its matrix or sampling medium may be necessary. There are relatively few cases where a judicious selection of separation techniques and laboratory analytical techniques fails to yield satisfactory analytical capabilities for an environmental analysis of interest. However, there may be cases where the technology is too time consuming and/or expensive for the particular application.

One major area in which our capacity for environmental assessment is technology limited is in the evaluation of inhalation exposures to complex mixtures of airborne organics. Another area is direct-reading instrumentation for chemicals which produce effects associated with their transient peaks rather than with their cumulative exposures. The need for direct-reading instrumentation is greatest for chemicals present as aerosols. Great progress has been made in the past decade in the development of continuous direct-monitoring devices for specific airborne gases and vapors. In contrast, there are no instruments available for the continuous measurement of the airborne concentrations of specific chemicals present in the atmosphere as aerosols. It is not possible, for instance, to currently monitor the concentration of sulfuric acid mist. The inability to do so has contributed to the failure to characterize the roles and effects of the various components of the overall SO_x mixtures generally present in the ambient air. The only direct-reading aerosol monitors currently available are those which measure physical parameters of the aerosol, e.g., size distributions, overall number or mass concentrations, and light scatter or extinction.

Human exposures to coal utilization effluents via drinking water contamination are relatively easy to monitor using available sampling protocols and analytical procedures. Exposures via food are, on the other hand, much more difficult and costly. Dietary sources among human populations are much more variable in composition and geographic origin, making it very difficult to do representative sampling. In addition, most of the contaminants generated by coal utilization technologies are also generated by a variety of other sources as well, making source attributions extremely difficult in most cases. Despite the real and potential difficulties, methodologies should be developed to assess the impact of coal use on toxic substances in food chains leading to man. Toxic trace elements such as Cd, Pb, and Hg, known to accumulate in biota, are of special interest. The U.S. Food and Drug Administration conducts regular market basket surveys for several toxic trace metals to assess human dietary exposure. The National Dairy Panel survey has developed fish consumption patterns for the U.S. population; this information, combined with analysis of trace contaminates in edible species of fish, allows quantitative estimation of the range of human intake. This approach has been used in assessment of human exposure to mercury and PCBs due to consumption of fish (National Research Council 1978).

The best, and perhaps only way, to determine the potential impact of the leaching of liquid and solid wastes on human tissue burdens via their transmission through irrigation and drinking water supplies is to determine the extent of the leaching from the drainage sites. Population exposures to certain toxic trace elements may be affected by reduced pH of ambient waters due to precipitation of acid rain. For example, when mercury is present in sediments in lakes, rivers, and other aquatic bodies, it is subject to methylation to both monomethyl and dimethylmercury compounds depending on the pH of the water. Low pH favors the formation of the monomethyl compounds that are more avidly accumulated in aquatic food chains (Sagerstrom and Jerelov 1972). Consequently, levels of methylmercury in several species of edible fish have become elevated above federal safety guidelines.

Low pH in rain water may increase concentrations of such trace metals as aluminum due to leaching. Aquatic species are the primary target for aluminum toxicity, but human exposure may occur via drinking water or through water used in hemodialysis (artificial kidney) machines. Lead levels in drinking water have also become elevated due to reduced pH which results in leaching of lead from metal pipes.

The adequacy of measurements made to evaluate the potential for health effects in a given situation can be judged by a variety of criteria or combinations of criteria. These include:

- Sensitivity, i.e., can the airborne concentrations capable of producing the health effects be measured at an acceptable level of accuracy.
- Specificity, i.e., can the contaminant of interest be measured in the presence of cocontaminants and background contaminants.
- Temporal resolution, i.e., can the peak concentrations of the contaminant of interest be determined with a resolution appropriate to the averaging time for the biological effect.

- Temporal responses, i.e., what is the interval between the time of air sampling and the availability of the concentration determined for the sample. This can vary from instantaneous for direct-reading gas phase sensors to months for laboratory evaluations of field-collected extractive samples.

- Spatial resolution, i.e., can the measurements be made at locations suitable for exposure evaluations. In other words, can the measurements be made using personal samplers or hand-held samplers or monitors at the breathing zone of the individual whose exposure is being determined.

A recent review of the current status of the available measurement techniques and some recommendations for research on environmental measurements was prepared by the Second Task Force for Research Planning in Environmental Health Science (1977).

Recommendations

1. There is a pressing need for community air monitoring to develop and test an instrument for the continuous measurement of aerosol acidity especially sulfuric acid (H_2SO_4). Time-averaged measurements of aerosol acidity and H_2SO_4 are also needed, and these also are currently beyond the state-of-the-art in routine monitoring.

2. Routine ambient air monitoring programs for potentially hazardous compounds are also needed. The sample collection and storage protocols need to be designed to minimize losses and uncontrolled transformations of the samples between their extraction from the air and their analyses. For organic aerosols, there may be a need for much larger volume samples than those currently collected, since many of the constituents of interest are present in extremely small concentrations. The samplers should include collection stages so that separate analyses can be performed on the aerosols within the characteristic size modes.

3. Mutagenesis and carcinogenesis assays of the ambient air should include compounds present as vapors. Very little is currently known about the contribution of the vapor phase organics to the overall hazard of the effluents of the coal utilization technologies, and there should be at least some exploratory investigations of their significance.

4. The technology for analysis of toxic metals (e.g., x-ray fluorescence) in the ambient air is relatively well advanced and should be transferred to routine monitoring programs associated with the coal utilization technologies.

5. Research is needed on sampling strategies and protocols for evaluating the extent of the chemical leaching to ground and surface waters from the waste depositories of liquid and solid wastes from the coal utilization industries.

6. Food contaminant monitoring activities should be expanded to provide data on additional categories of contaminants.

7. Coal-related pollutants in drinking water should be identified in a few key locations near coal mines, coal-fired power plants, and coal waste disposal sites.

8. Monitoring soil and dust samples in selected communities near coal combustion sources (e.g., power plants) should be implemented on a regular basis. This will allow an estimate of the amounts of pollutants ingested by children with pica or who suck their fingers.

4.0 EFFECTS SPECIFIC TO INDIVIDUAL COAL TECHNOLOGIES

4.1 Extraction, Transportation, and Storage of Coal

4.1.1 Coal Mining

Coal, in addition to carbon, also contains varying amounts of water, combustible gases and other volatile materials, and mineral impurities such as organic sulfur, silica, pyrites, calcium and magnesium carbonates, phosphates, and clay. During the formation of coal, movement of the earth's crust caused cracks and crevices which were filled by mud deposits of shales and pyrites. Intrinsic within coal is ash, largely withdrawn from soil and incorporated into biomass by the original vegetation. Therefore, coal has no fixed chemical composition but varies widely according to the amount of inorganic impurities, its basic carbon content, and its stage of development. Most of the environmental contamination associated with coal is a direct result of these components of coal and substances in the ash.

Coal dust emissions in underground mines have long been recognized as the most important physical hazard to the health of coal miners. Activities associated with the use of modern extraction machinery and the increased rate of extraction are known to have increased the levels of particles in the air of underground mines over those present in the days when the pick and shovel were the principal method of extraction.

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Underground coal mining, because of the confined working area, does not pose a problem to ambient air quality in itself, except around surface facilities and dump areas. It does, however, pose a potential for occupational exposure to airborne dust. Careful design and maintenance of these facilities can prevent such airborne dust from becoming a major pollutant either to the ambient or to the occupational environment. Exposure to coal dust can result in a variety of lung-related diseases such as emphysema and pulmonary fibrosis (i.e. black lung disease).

Dust presents a major environmental problem during surface coal mining and reclamation in Western coal fields, particularly where high winds and low rainfall are present. The impact of this emission on society is reduced by the fact that most Western mine developments are in sparsely populated regions. Dust problems also occur in Eastern and Midwestern coal surface mines where dust occasionally blows from roads, strip pits, trucks, and railroad cars.

The abatement of fugitive dust pollution associated with surface mining requires proper planning. Haul and service roads must be surfaced with asphalt, oiled, or kept damp with water. Oiling of roads may not be the best dust suppression method since many areas come in close contact with surface and ground water. Mined areas need timely reclamation and seeding to prevent wind erosion of spoil piles. Planning is essential in designating areas of potential dust pollution and utilizing the best methods possible to keep airborne dust at an acceptable level.

A maximum shift average occupational exposure of 2 mg/m3 of respirable coal mine dust in active mine workings was established, effective January 1, 1973, under the Federal Coal Mine Health and Safety Act of 1969. It is generally agreed that, as a result, coal mines in the United States are significantly less dusty than they were a decade ago. For example, operators of underground mining machines were exposed to between 3.9 and 6.5 mg/m3 of respirable coal mine dust during 1968-69; now they are exposed to between 1.3 and 1.8 mg/m3 (National Research Council 1980).

Despite the success of the Act, concerns about the control of respirable coal mine dust remain. Miners and union officials contend that the present personal samplers are an encumbrance to wear and do not necessarily reflect personal exposure to respirable dust accurately since dust levels are often lower when it is known that samples will be collected. Mine operators are concerned that changes in the present methods of enforcing compliance are likely to be counterproductive in the absence of adequate understanding of the formation and behavior of clouds of respirable coal mine dust. Mine operators are also worried that introduction of more productive mining methods (such as longwall mining) would be prohibited. Federal agencies are concerned about the proper enforcement of the Act to ensure the health of coal mine workers, and to control the costs to the Federal government of compensatory payments to affected mine workers which are primarily attributable to previous high dust exposures.

Currently these costs are close to $1 billion annually (National Research Council 1980).

Some controversy exists over the accuracy of the two-stage cyclone-filter personal sampler units and methods of analyzing the measurements. In a "Final Report to the Senate Committee on Labor and Public Welfare" on "An Evaluation of the Accuracy of the Coal Mine Dust Sampling Program Administered by the Department of the Interior," the National Bureau of Standards concluded that:

- Both the weighing process and the intrinsic variability in the performance of the personal sampler unit in laboratory studies contribute coefficients of variation of 7 percent when making a single dust measurement at a concentration near the level of 2 mg/m^3.

- Personal sampler units operated adjacent to one another and stationary in a mine can give a coefficient of variation of 7 percent when used with meticulous care. This is consistent with the laboratory findings concerning the performance of sampler units.

- In the absence of such care, the coefficient of variation has been found to be much greater than 7 percent. The coefficient of variation is estimated to be 30 percent when the personal sampler unit is operated by untrained personnel. This figure does not allow for various abuses of the sample unit encountered during routine mining operations.

In a 1976 document, "Statistical Analysis of Mining Enforcement Safety Administration Respirable Dust Data," the National Institute for Occupational Safety and Health (NIOSH) analyzed measurements using personal sampler units from at least 40 shifts from each of 22 high-risk mine sections. NIOSH found that the coefficient of variation between shifts was 91.6 percent (1976). Therefore, the variations in the dust concentrations within the mine environment far exceed the variations in the instrument itself.

Underground mining, blasting, coal cutting, and loading can release methane, dust, noxious fumes, and other air pollutants. Exhausts from internal combustion engines, especially diesel engines in power vehicles and equipment, emit pollutants which pose a threat to human health. Although most equipment in underground mines is electrically powered, one or more pieces of diesel equipment are found in about 50 mines (Wheeler 1979). Most of the diesel equipment is used in the West.

In a properly ventilated mine, carbon monoxide is probably not an important toxic factor. Oxides of nitrogen, although representing a relatively large percentage of the toxic constituents of diesel exhaust (where present) are not considered a major toxic problem since airflow in a properly ventilated mine would tend to remove nitric oxide, the major oxide of nitrogen, long before it is oxidized to nitrogen dioxide, a much more toxic nitrogen compound. Sulfur dioxide emissions are controlled due to stringent regulations of the sulfur content of diesel fuel.

Polycyclic aromatic hydrocarbon (PAH) compounds, however, have been identified as the most potentially hazardous agents found in diesel engine exhaust. Although a properly maintained diesel engine would be likely to emit only small quantities of these compounds, the possibility that they may be carcinogenic to mine workers singles them out for careful attention. Such hydrocarbons within diesel engine exhaust gases that have been measured include benzo(a)pyrene at one to 422 parts per billion, from one to 533 parts per billion for benzo(e)pyrene, and one to 466 parts per billion for benzo(a)-anthracene. Other hydrocarbons observed in diesel engine exhausts include chrysene, pyrene, anthracene, phenanthrene and its derivatives, fluoranthene, and phenols (Environmental Health Associates 1978).

Aldehydes also are present in diesel exhaust emissions as a result of unburned hydrocarbons. The acute toxicity of aldehydes is related to their capacity to cause eye and respiratory tract irritation. Two specific aldehydes, formaldehyde and acrolein, are of particular importance because of their biologic effects including cancer and their presence in higher concentrations in diesel exhaust than other aldehydes.

Although concentrations of methane in mine atmospheres have been studied extensively, relatively little work has been done on the distribution of concentrations of respirable coal mine dust. In one study of the latter, 10 samplers were mounted at different positions on a continuous mining machine within several feet of the operator, and measurements were made over full shifts at six different mines. The results showed steep gradients, of the order of 1 mg/m^3 per foot of distance, in the concentration of respirable coal mine dust in the vicinity of the operator. Therefore, the extent to which measurements of airborne respirable coal mine dust made with machine mounted samplers reflect operator exposure is highly questionable in the absence of a better understanding of the spatial and temporal characteristics of the concentrations of such dust than now exists. At present, similar reservations must apply to any sampler other than personal sampler units.

From these data and the state-of-the-art of dust measurement, the National Research Council Committee on Measurement and Control of Respirable Dust in Mines (1980) concludes that current sampling technology is adequate for measuring concentrations of respirable coal mine dust and that the large variations arise from spatial and temporal changes in concentrations of such dust.

Since personal samplers only measure dust concentration integrated over a working shift, instruments are being developed that can give instantaneous readings of local dust concentrations. These instruments can be used as stationary monitors or as survey instruments (that is, not as personal sampler units) for gathering data on time and space variations in dust concentrations to allow improvements in mining practices and dust control. The National Bureau of Standards concluded that stationary monitors should complement personal sampler units for determining exposure of miners to respirable dust.

The MRE sampler which has a horizontal-elutriator preceding a filter is generally considered to be the best reference sampler unit.

It is intended to be used in a stationary position for obtaining gravimetric samples of respirable coal mine dust averaged over periods of time and many hours. The SIMSLIN II is similar to the MRE sampler, but incorporates a photometer to allow instantaneous concentrations of dust to be measured as well. Other photometric samplers with different attributes, such as the Tyndallometer, the SRI Portable Mine Dust Concentration Instrument and the new GCA photometer, have been developed. Under development are single-particle-counting photometers which enable the sizes of dust particles to be determined individually and collectively. In addition, instruments have been developed that measure the mass of a sample collected by impaction, filtration, or electrostatic precipitation. These include instruments designed specifically for coal mine use, such as the GCA Respirable Dust Monitors which use beta-ray attenuation for mass detection. They also include instruments developed for uses other than coal mining, such as the TSI Piezobalance or the QCM cascade, which use piezoelectric quartz crystals as mass sensors. The principal use of these instruments in the foreseeable future is for research on the spatial and temporal as well as the size and/or compositional characteristics of respirable coal mine dust in the mine atmosphere. The National Research Council's Committee on Respirable Dust in Mines concluded that the basic technology for measuring respirable coal mine dust in mine atmospheres is available and sufficient to meet research needs, although further development and calibration of research instruments will be required (1980).

Historical data indicate that coal mining is a dangerous occupation. Quantitative estimates of injury and death rates for the fuel cycle (excluding end use) are provided in Table IX (data prior to 1976) and Table X (data for 1978). The majority of occupational deaths and injuries occur in the underground mining and transportation sectors. Table XI compares the underground coal mining risks with risks from other industrial activities. The threat to personal health or safety from mining accidents depends upon the extraction technique used, the location of the mine, the activity of the miner, the location of the individual inside the mine (underground miners), the experience of the mining crew, the equipment used, the safety precautions and procedures employed in the mine, and other factors. Roof, rib, and face falls accounted for about 50 percent of yearly mine fatalities until the mid-1960s and still are the most important cause of mine fatalities (Brown 1979). Roof and rib falls also accounted for a substantial part of the nonfatal coal mining accidents. Although the number of persons hurt by a single roof or rib fall is small, the high frequency with which they occur, however, leads to a high death and injury total.

The second greatest hazard in underground mining involves mining equipment operation. An engineering safety analysis identified the need for standardization of controls for mining equipment, noting that the positioning and responsiveness of equipment controls depended on the manufacturer. Two causes of fatalities are often

TABLE IX

ANNUAL DEATHS, INJURIES AND WORK DAYS LOST FOR UNCONTROLLED COAL-FIRED ELECTRICITY SYSTEMS AWSOCIATED WITH A 1000 MEGAWATT POWER PLANT WITH A LOAD FACTOR OF 0.75

OCCUPATIONAL HEALTH	EXTRACTION		PROCESSING	TRANSPORT	CONVERSION	TRANSMISSION	TOTAL	
	DEEP	SURFACE					DEEP	SURFACE
Deaths	1.67	0.308	0.0238	2.30	0.012	NA	4.00	2.61
Injuries	85	13.9	2.56	23.4	1.38	NA	112.3	41.2
Workdays	4,678	499	99.5	2,340	152.9	NA	15,280	3,091

NA - not available

SOURCE: U.S. Environmental Protection Agency 1977. Accidents and Unscheduled Events Associated with Nonnuclear Energy Resources and Technology. EPA 600/7-77-016. Office of Research and Development, Washington, D.C.

NOTES:

Impacts of coal based on coal transport exclusively by rail (ave. distance 300 ml.); annual coal supply for a 1000 MWe plant is 0.1 percent of total national ton-mileage and it is assumed that average injury leads to loss of 100 workdays.

For conversion it is assumed that one-half the combined deaths and permanent injuries are fatal injuries. Permanent total disabilities are considered to represent 6,000 workdays lost, and other disabilities are estimated at 100 days lost.

Workdays lost due to pneumoconiosis not included in data on deep mines.

TABLE X

FATAL, DISABLING AND NONDISABLING INJURIES OF 1978, FOR COAL AND METAL/NONMETAL MINES

	Fatal Injuries	Fatal Incidence Rate	Nonfatal With Days Lost (NFDL)	NFDL Incidence Rate	Nonfatal Injuries With No Days Lost (NDL)	NDL Incidence Rate	All Injuries	All Incidence Rate	Average Number of Workers	Employee Hours Reported
Coal Mines										
Underground Mines:										
Underground	66	.07	9,864	10.62	2,337	2.52	12,267	13.21	125,936	185,703,725
Surface	9	.07	652	5.85	313	2.81	973	8.73	15,425	22,280,422
Total, Underground Mines	75	.07	10,516	10.11	2,650	2.55	13,240	12.73	141,361	207,984,147
Surface Mines										
Strip Mines	16	.03	2,019	3.36	1,351	2.25	3,386	5.64	72,228	120,110,438
Auger Mines	1	.26	21	5.53	5	1.32	27	7.11	1,109	759,732
Culm Bank	-	-	11	6.74	-	5.52	20	12.26	328	326,354
Dredge	-	-	2	19.98	-	-	2	19.98	21	20,022
Total Surface Mines	17	.03	2,053	3.39	1,365	2.25	3,435	5.67	73,686	121,216,546
Preparation Plants	13	.08	851	5.42	489	3.11	1,353	8.61	21,607	31,411,786
Independent Shops/Yards	-	-	134	4.40	100	3.28	234	7.69	3,883	6,089,076
Total Other Operations	13	.07	985	5.25	589	3.14	1,587	8.46	25,490	37,500,862
TOTAL	105	.06	13,554	7.30	4,604	2.51	18,262	9.96	240,537	366,701,555

SOURCE: Bureau of Mines, 1977.

TABLE XI

INJURY RATES IN SELECTED INDUSTRIES, 1973[a]

INDUSTRY	FREQUENCY RATE[b]	SEVERITY RATE[c]
Automobile	1.60	176 (110)[d]
Chemical	4.25	397 (93)
Machinery	5.81	331 (57)
Petroleum	6.73	690 (103)
Shipbuilding	7.08	653 (92)
Non-ferrous metals and products	9.31	712 (76)
Mining, surface[e]	9.75	1365 (140)
Tobacco	12.03	404 (34)
Construction	13.59	1544 (68)
Railroad equipment	14.23	1361 (96)
Quarry[e]	17.67	1825 (103)
Underground mining, except coal[e]	25.26	4431 (175)
Underground coal mining[e]	35.44	5154 (145)
All industries[f]	10.55	654 (62)

[a] The data were reported by member companies of the National Safety Council. NSC members generally have better safety programs and lower injury rates than non-member companies. Data are not comparable to Bureau of Labor Statistics (BLS) rates for less severe injuries (requiring medical treatment but not involving days of disability).

[b] Disabling injuries per 10^6 man-hours.

[c] Lost time (hours) per 10^6 man-hours.

[d] Average days charged per case.

[e] Based on data for 1972.

[f] Rates not fully comparable from year to year due to reporting inconsistencies.

SOURCE: U.S. Environmental Protection Agency 1977 some form of coal transport are 0.06 fatal injuries and 0.585 nonfatal accidents for every 10^{12} Btu equivalent tons shipped. Comparable analyses indicate slurry pipeline accident rates of 0.0019 fatalities and 0.032 nonfatal injuries for 10^{12} Btu transported. Trucking rates are estimated at 0.032 fatalities and 0.69 nonfatal injuries for 10^{12} Btu energy shipped (U.S. Environmental Protection Agency 1977). These accident projections are based on national statistics for motor freight carriers where assumed coal shipment accident rates are represented as the coal shipped to total freight carrier tonnage for the time span in question. This assumes that the transport of coal presents no additional accident potential than the generic rate for all motor carrier transports. This assumption may not hold in those regions (e.g., Appalachia) where steep, unimproved roads may exist.

Recommendations

1. In coal transport, accidents involving the workers are a significant feature. Efforts must be made to improve the safety during transport. The possible health effects on the workers of additives such as surfactants used in coal slurry transport should be investigated.

4.1.3 Coal Storage

A total of 124×10^6 metric tons (137×10^6 tons) of coal was stockpiled in the United States in 1975 (U.S. Environmental Protection Agency 1978a). The major hazards to human health result from rainfall and subsequent deterioration of ground water quality as rainwater, which drains through the coal piles and fires, reaches underground aquifers. The water problem is considered in detail by the ecological effects working group and will not be dealt with here.

Fires from coal refuse banks and mines release smoke, airborne particles, and noxious, sometimes lethal, gases. There are an estimated 250 x 106 metric tons of burning refuse bank material (U.S. Environmental Protection Agency 1978a). Burning of coal piles, impoundments, abandoned mines, and outcrops results in emissions of various pyrolytic and combustion products such as particulate matter, nitrogen oxides, sulfur oxides, carbon monoxide, hydrogen sulfide, ammonia, polycyclic organic materials (POM), and hydrocarbons including benzene, toluene, and xylene. Trace elements such as arsenic, boron, and mercury are also emitted (U.S. Environmental Protection Agency 1978b).

The spontaneous heating of coal and coal refuse piles is mainly an oxidation phenomenon involving coal, associated pyrite, and impure coal substances. It is also influenced by the presence of moisture. The oxidation of carbonaceous and pyritic material in the coal refuse is an exothermic reaction in which the temperature of a pile or portions of it will increase if the amount of circulating air is sufficient to cause oxidation but insufficient to allow for dissipation of heat. The temperature of the refuse then increases until ignition temperature is reached.

Emissions from fires in coal refuse piles, abandoned mines, and outcrops contribute 0.001 percent of the particulates, 0.16 percent cited by members of the mining industry--lack of mining experience and lack of job task experience.

Less frequent accidents leading to deaths involve underground fires and surface mine accidents. Although explosions and fire are often the most newsworthy accidents associated with underground mining, only 10 to 12 percent of the annual mining fatalities were caused by these disasters from 1960 to 1970 (U.S. Environmental Protection Agency 1977). Although the frequency of injury and death at surface mines is significantly less than in underground mines, the number of accidents occurring at surface mines has been increasing because of increasing reliance on surface mining techniques.

Recommendations

1. Samples of respirable coal mine dust large enough to be characterized chemically, morphologically, and physically should be collected for analysis and some of them stored cryogenically for future reference.

2. Research is needed on the fundamental mechanisms by which fragments are produced in coal mining; how some of these fragments in the respirable size range become airborne; and the spatial and temporal characteristics of respirable coal mine dust atmospheres. The mechanism of fragmentation needs to be understood so that machines can be designed to produce the least amount of coal mine dust in the respirable size range. Entrainment needs to be understood so as to minimize the proportion of the dust that is entrained. The spatial and the temporal characteristics need to be understood so that the exposure of workers to the dust can be controlled.

3. Variations in the composition and other characteristics of respirable dust from different coal seams should be studied, because it has been demonstrated that factors other than concentration significantly affect the incidence of coal mine workers' pneumoconiosis. Samplers other than personal sampler units will be needed.

4. Accidents in underground mining and coal workers' pneumoconiosis together have been the major hazards to health and safety in the past. Strict enforcement of the Federal Coal Mine Safety and Health Act of 1977 should further reduce the risks to workers in the coal industry. Even with strict enforcement, in order to be certain that present standards provide adequate protection, effective health monitoring and assessment will be necessary. This should include air monitoring in the workplace and a better characterization of the particle size distribution and the chemical composition of the various size groupings.

5. Continued improvement in miners' safety will require increased education, especially for new miners. Such safety programs must have complete and strong support from management.

6. New developments, such as use of diesel-powered underground equipment, will require study of potentially deleterious health effects.

4.1.2 Coal Transport

Coal haulage in coal mining operations currently accounts for between 10 and 15 percent of mining fatalities. In underground mining operations, the haulage accounts for about 72 percent of total haulage accidents, and for 61 percent of all haulage-related man-days lost. A worker at the controls of a vehicle is in a more dangerous location than a worker performing supporting tasks. Workers at the controls are involved in 82 percent of total haulage-related accidents, and account for 69 percent of the total man-days lost (U.S. Environmental Protection Agency 1977).

Rail systems transport to the consumer approximately 66 percent of the coal produced, 22 percent in unit trains, and 44 percent via mixed trains. Coal shipments represented 27 percent of total rail freight in 1969 and 1970. Estimated rail accident rates involving of the nitrogen oxides, 0.14 percent of the sulfur oxides, 0.14 percent of the hydrocarbons, and 4.9 percent of the carbon monoxide emitted nationally (Brown 1979).

4.2 Processing and Conversion Technologies

4.2.1 Chemical Coal Cleaning

Impurities in coal can be divided into two general classifications: inherent, and removable. The inherent impurities are chemically combined with coal and require chemical coal cleaning methods for removal. The removable impurities are extraneous and can be eliminated by crushing and separation to the extent that this is economically justified.

Many pollutants associated with physical coal cleaning are identical to those from extraction namely acid drainage, refuse leaching and burning, and fugitive dust. Since the process is conducted for the purpose of reducing the concentration of undesirable mineral impurities in coal, it is to be expected that the handling and containment of these substances may present a major problem to the industry. Also included with these wastes are flocculants and other chemicals used in and resulting from reactions during the cleaning process.

The predominant group of impurities removed by physical coal cleaning which presents a health and environmental problem are the trace metals. These include barium, cobalt, copper, nickel, rubidium, strontium, yttrium, zinc, and zirconium (Brown 1979). Generally, the concentrations of certain elements in the organic phase such as aluminum, calcium, iron, silicon, manganese, and arsenic are relatively low and are more likely to be associated with the removable mineral matter. Those strongly associated with the organic matter and not readily susceptible to washing include antimony, beryllium, boron, germanium, and vanadium. The concentrations of trace elements tend to vary among coal beds within a region and also from region to region. Generally, the available data indicate that toxic trace elements tend to concentrate in the heavier specific gravity fractions of the coal, indicating that they have an affinity for mineral matter. In removing this matter, coal-washing plants can reduce trace element concentrations as much as 88 percent, bringing them nearer to environmentally acceptable levels (Cavallaro et al. 1978).

The aqueous drainage from coal refuse is usually contaminated by acids and dissolved or suspended mineral matter. The higher concentrations of dissolved species are found in the more highly acidic solutions. Typically, the acid drainage from coal refuse contains high concentrations of iron, aluminum, calcium, magnesium, and sulfate ions which are derived from the major coal mineral complexes (Cavallaro et al. 1978). Recently, some of the minor or less abundant trace elements have been identified in the drainage or leachates from coal refuse or spoils, but a thorough assessment of this subject has not been made. There is considerable evidence that coal refuse dumps will continue to produce significant quantities of water-borne contaminants for many years after their disposal.

The effects of drainage from coal wastes can have a marked effect on surface and ground water. In a recent study of the effects of coal waste drainage in a Pennsylvania coal mining area, the mineral and trace element contents of the water from several springs and a number of surface waters were analyzed. Among the constituents measured were iron, manganese, aluminum, zinc, cobalt, nickel, copper, chromium, cadmium, silver, and lead (Torrey 1978). Iron and manganese were found to be greatly in excess of local drinking water standards for all of the water samples and the concentration of zinc, chromium, copper, and cadmium exceeded these standards in some of the ground waters. Generally, the trace metal concentrations were higher in ground water samples than in the surface waters. A compilation of the ranges of concentrations of dissolved species for all of the water samples studied is given in Table XII.

One of the main issues related to coal preparation wastes is the importance of pH in determining the levels of trace element contamination in refuse drainage. Recent studies have shown that under all conditions of static and dynamic leaching, an inverse relationship prevailed between pH and the amounts of elements leached from the refuse samples. Thus, at low pH (2 to 3), worrisome quantities of trace elements were leached from all of the samples studied; whereas, in those systems where the leachate was more nearly neutral (pH from 5 to 7), trace element leaching and the capability of the leachates to solubilize contaminants were minimized. Therefore, preventing the

TABLE XII

QUALITY OF SURFACE AND GROUNDWATER IN A PENNSYLVANIA COAL-MINING REGION

	Mean[a]			
Variable	PPM	PPB	Range[b]	Water Standard[c]
pH*	4.24[d]		2.69 - 6.78	6.0 - 8.5
*	1625[e]		222 - 7000	<625
Monovalent Cations				
Na	15.9		0.8 - 70	
K	4.8		1.5 - 11.4	
Ag		0.54	0.0 - 3.1	<50
Divalent Cations				
Mg	120		5.8 - 985	
Ca	104		3.0 - 312	
Fe(II)*	61.5		0 - 510	<0.3
Mn*	29		0 - 281	<0.05
Zn	1		0.001 - 14.5	<5
Ni	0.69		0.04 - 7.5	
Co	0.5		0.01 - 4.98	
Cu		29.6	1.5 - 410	<1000
Cr		10.8	0 - 120	<50
Cd		3.6	0.3 - 13.1	<10
Pb		1.8	0 - 7.0	<50
Trivalent Cations				
Fe(III)*	19.7		0 - 102	<0.3
Al	13.2		0 - 201	
Neutral				
SiO_2	10.3		2.9 - 70	
Monovalent Anions				
Cl	204		0 - 129	<250
HCO_3	13.9		0 - 122	
Divalent Anion				
SO_4*[f]	985		28 - 6230	<250

*The average of this variable exceeds the water standard.

[a] PPM = parts per million, PPB = parts per billion.

[b] Range units same as for mean.

[c] Recommended local drinking water standards (units same as for mean).

[d] pH units

[e] Micromoles at 25°C.

[f] Much as HSO_4

SOURCE: Torrey 1978.

formation of acids in refuse dumps, or neutralizing the acid drainage as it is formed, should prove effective in controlling trace element releases into the environment.

Coal preparation wastes are generally discarded wet or damp, which is very likely to lead to pyrite oxidation. Also, wastes discarded in the Midwest and East often receive substantial amounts of rain before they are covered. These generally drain, but remain damp for long periods allowing oxidation and trace element leaching.

The most common processes for achieving such physical separations are based upon the difference between the specific gravities of the impurities and that of the coal. Simply stated, coal has a specific gravity of about 1.3, which is less than that of its impurities (Brown 1979). Thus, when the free particles of coal and impurities are distended in water or some other heavy medium intermediate between coal and rock, a separation occurs as the heavier and undesirable particles settle at a faster rate than the coal. In commercial-scale cleaning operations, it is not uncommon to process 500 to 1,000 tons of coal per hour, using a variety of equipment designed specifically for the makeup of the particular raw coal being processed and the desired end product (U.S. Environmental Protection Agency 1978b).

Generally, physical coal-cleaning processes are classified as (1) gravity-based stratification, or (2) nongravity processes. Included in the first category are such wet processes as dense media processes, pneumatic processes, launder washers, jigs, classifiers and tables; the nongravity category includes froth flotation. Some other techniques being currently evaluated include thermal-magnetic separation, immiscible liquid separation, selective flocculation, electrokinetic separation and two-stage froth flotation (Kilgore 1976.)

The potential occupational health hazards in these processes are: exposure to high levels of coal dust and noise during coal crushing, and exposure to solvents and additives from the liquid baths used in the gravity or flotation-based separation techniques. There do not appear to be any significant methodology problems in measuring the occupational exposures, provided the toxicants to be measured can be specified.

In chemical coal cleaning, the coal may be reduced to very small sizes and the finely powdered coal dust can ignite spontaneously resulting in an explosion. The severity of the explosion will depend on the space, the dust concentration, the amount of available oxygen, and the nature of the area in which it occurs (Wilson 1977). Some of the coal cleaning processes such as the JPL, the Syracuse, the Ames, and the Battelle processes may represent explosion hazards due to their generation of fine coal dust. Research may be needed on techniques to control coal dust explosion hazards within process vessels.

Other occupational health problems in chemical coal cleaning may be associated with vapor and gaseous emissions that may occur during the various coal cleaning processes as a result of normal venting and bleeding operations or as a result of accidents. The nature of the releases varies from process to process and according to where in the process stream the release occurs.

During the Magnex coal cleaning process, carbon monoxide and iron pentacarbonyl are formed and may be released with vented vapors; even with a CO recirculation system, some release may occur due to bleeding (Contos 1978). Metal carbonyls are extremely toxic. Since many coals contain small amounts of nickel and other trace metals it is possible that carbonyls might be formed.

Several of the chemical coal cleaning processes have the potential for release of acid vapors with the vent gas. The amount released will be a function of the scrubbers or other control devices. The JPL process may release both H_2SO_4 and HCl while the PETC process may result in H_2SO_4 release (Friedman 1979; Contos 1978).

In addition to the potential release of acids, the JPL process uses large quantities of methyl chloroform (1,1,1-trichloroethane) in chlorination processes. Other as yet unidentified chlorinated organics may be released from this process as well as methyl chloroform.

A number of the chemical coal cleaning processes may also result in the release of nitrogen oxides. Of particular concern for NO_x are the KVB and the Ames processes. The Battelle and G.E. Chemical

Coal Cleaning processes have the potential to release hydrogen sulfide.

The technology for measuring occupational exposures to these chemicals appears to be adequate for the exposure evaluations that need to be performed.

The G.E. Chemical Coal cleaning process uses microwave irradiation to rapidly heat caustic-impregnated, ground coal. The present laboratory-scale experiments use radiation sources of a 1kW, 2.4 GHz, or a 2.5 kW, 8.35 GHz generator (Contos 1978). With the use of the powerful microwave generators required to clean coal by this process on a commercial scale, some occupational exposure to microwaves due to incomplete containment could be expected.

Measurements of microwave field intensities in the workplace will be needed, and can be performed with available survey instruments.

The solid wastes that result from most of the coal cleaning processes will be high in their content of trace metals, especially iron. Other metals such as Ni, Hg, Cd, Pb, and Be, which have known adverse physiological effects, may also be expected to be present (Contos 1978). If these solid wastes are not properly disposed, leaching may occur which could result in the eventual entry of the trace metals into the drinking water supply or into the food chain.

Recommendations

1. In physical coal cleaning there is a potential for significant exposure to coal dust, especially to maintenance

personnel who must repair equipment in the event of a breakdown or failure. When solvents are used for extraction or flotation processes, the effects of these solvents and mixtures on health must be evaluated.

2. In the chemical coal cleaning processes a variety of methods have been suggested since each can pose specific problems such as exposure to metal carbonyls in the Magnex process, microwaves in the G.E. process, acid mists in the PETC or JPL processes, or a variety of metals as a result of the concentration/extraction processes. Each process needs to be carefully evaluated as to its potential effect on the worker's health. Appropriate control measures must be instituted.

4.2.2 In Situ Gasification

In situ gasification will involve a number of different operations with potential occupational health considerations. There will be some mining and tunneling operations prior to underground ignition. As a result, there will be dust generation requiring engineering controls to maintain acceptable dust levels. In new workings within an ongoing processing region, there may also be underground fissures which permit entry of gasification effluents from the older workings being gasified. Thus, underground exposure monitoring should include measurements of combustion effluents as well as dust.

It is possible that the use of explosives to fracture underground coal seams could result in the creation of fissures not connected to the vent gas system. Should this occur, various kinds of gases, volatilized elements, and partially combusted hydrocarbons might be released to the surface resulting in occupational and/or general population exposures. The trace gases and volatiles which are likely to escape during coal combustion should include: ammonia (NH_3), hydrogen cyanide (HCN), hydrogen sulfide (H_2S), carbonyl sulfide (COS), carbon disulfide (CS_2), sulfur dioxide (SO_2), methyl mercaptan (CH_3SH), thiophenes, thiocyanates, trace organics, and volatile trace elements such as Li, V, F, Na, K, Ca, Cl, Hg, As, Pb, Cd, and Se (Jones et al. 1977). The trace organics which might be emitted during combustion are generally not well characterized.

The gases and volatiles released during coal combustion are similar to those which could be expected later during the cleaning and upgrading of the product gas. Various sulfur-trapping devices on the product streams are effective against SO_x and H_2S, but COS and CS_2 may pass through and, if they do, represent significant exposure hazards.

Despite the fact that many incompletely combusted organics are strongly bound to the coal surface, some of the most soluble will be dissolved in the ground water. These will include pyridines, quinolines, indoles, and phenols (Pellizzari 1978). Since the exact identities of the compounds are unknown, it is difficult to determine the magnitude of the potential effects should these complex organics reach the drinking water supply or the food chain. These classes of highly water-soluble organic compounds include known and suspected carcinogens, irritants, and compounds of high toxicity.

Some of the trace elements such as Hg, Cd, As, Se, and F also exist in a soluble form and, if present in sufficient concentrations, could result in toxic effects. This would occur through drinking water exposure and through concentration of these trace metals up the aquatic food chain.

The quantities of contaminants in effluents from in situ coal gasification have not been adequately characterized. This is especially true for contaminants, e.g., organics, trace elements that may appear in trace quantities (Pellizari 1978). Aqueous discharges at different stages of coal conversion (pregasification, conversion, and wastewater treatment) may differ in nature and quantity. The potential trace contaminants from each of these processes may also vary by site according to coal type, operational design, and plant size. Once a particular site is characterized, a problem arises in predicting the extent of penetration of tars and pyrolysis products through the coal or surrounding rock.

Recommendations

1. The major difficulty in measuring the emissions to the atmosphere from in situ coal gasification is in identifying the vent sites. Hence, characterization of the extent of the emissions requires the development of strategies for assembling the sampling networks and meteorological data resources needed for such evaluations.

2. The quantities and biological activities of the contaminants in effluents from in situ coal gasification should be determined.

3. In situ coal gasification can result in extra cracks or fissures through which various noxious gases can escape and expose workers to significant levels. These gases can include ammonia, hydrogen cyanide, carbon monoxide, and hydrogen sulfide as well as a variety of organic compounds. For many

of these, the effects on health are known. For others, such as some of the complex organics, little is known concerning their effect on the health of workers. It will be necessary to monitor the areas where in situ coal gasification is done to ensure that exposure of the workers is minimal.

4.3 End Use Technologies

4.3.1 Conventional Coal Combustion

The environmental contaminants produced by the burning of coal in boilers, power generators, and other stationary sources have been the subject of significant study. The oxides of sulfur, nitrogen, and carbon are the most abundant air contaminants produced by the combustion of coal. In 1974, about 20 million tons of SO_2 and 5 million tons of nitrogen oxides (NO_x) were discharged into the environment from coal burning (Brown 1979). In addition to these gaseous contaminants, coal combustion also produces large quantities of finely divided mineral particulates (flyash) that also escape into the environment. The ash contains toxic trace elements such as lead, mercury, arsenic, and cadmium (Brown 1979). These elements may also be present as vapors as well as adsorbed on the surface of flyash or other fine particle emissions. To lessen the air pollution load, increasing amounts of flyash are being removed from the stack components by precipitators and other devices.

Conventional coal burning can lead to exposures of workers to SO_2 depending upon the amount of sulfur in the coal dust. Exposure can occur during the addition of the coal to the burners or as a result of "blow backs" through the furnace door. Even though the ash may be handled mechanically, there can be breakdowns or failures that will require maintenance personnel to enter the ash hoppers. Significant exposures can occur during these procedures.

Coal generally contains minor traces of radioactivity; concentrations are highly variable and range from 0.001 to 1.3 picocuries per gram (U.S. Environmental Protection Agency 1978b; U.S. Energy Research and Development Administration 1977). Radioactive releases of uranium, radium-226, thorium, and their daughter products may result from the burning of both Eastern and Western coals, with the amounts of each emission depending on the source of the coal. These radioactive elements are not entirely released in stack gases; large quantities of radium remain with the ash. The estimated annual release rates for radionuclides from a 1000 MW(e) coal fired powerplant result in 0.04 to 0.35 mrem/yr whole body dose as a maximal annual dose committment per individual (Van Hook 1977). In assessing the radiation dose from coal combustion, it is useful to compare the average dose equivalent rate for the whole body from natural sources which is 80 ± 40 mrem/yr. with that for coal combustion of 0.007 mrem/yr. The panel did not address the radioactive releases from coal in detail and tended to agree with Van Hook (1977) that "atmospheric releases of radionuclides from increased coal combustion do not represent a significant public health problem unless coal containing greater than 5 ppm uranium comes into general use. Radiation releases from ash disposal sites have not been evaluated."

Accurate measurement of emissions is difficult, especially with regard to the measurement of fugitive emissions and of the more volatile constituents in the stack discharges. Furthermore, as the importance of the fine particulates is recognized, it becomes more important to measure the concentrations and compositions of the fine primary particulates as well as the concentrations of the condensibles which form or condense on fine particulates in the atmosphere.

Air pollution "episodes" of the Meuse Valley, Belgium in 1930, of Donora, Pennsylvania in 1948, and of London in 1952 and 1962 provided clear and dramatic evidence that the atmospheric products of uncontrolled combustion of fossil fuels can be lethal to exposed populations. In the larger cities of New York and London, several hundred to several thousand excess deaths were attributed to each of the several 2 to 4 day episodes reported in the 1950s and early 1960s. Concentrations of the sulfur oxide/particulate complex (SO_2 and particulates were the only indices of air pollution monitored) generally exceeded 1000 $\mu g/m^3$ during these episodes (Schrenk et al. 1949; Greenberg et al. 1963; Ministry of Health 1954); these levels are 3 to 4 times existing U.S. air quality standards.

Following recognition of the significant mortality effects of uncontrolled air pollution, a number of epidemiology studies focusing on disease and dysfunction in exposed populations were initiated in an attempt to identify the overall public health impact of the air pollution typical of many urban areas in the 1950s and 1960s. These studies have been reviewed in a number of comprehensive reports (National Academy of Sciences 1973, 1974; Coffin and Stokinger 1977; Royal College of Physicians 1970; American Thoracic Society 1978). The major health effects attributed to the sulfur oxide/particulate complex and the levels at which adverse effects might be expected in some exposed individuals are presented in Table XIII, which is taken from a report of a World Health Organization expert committee on air quality criteria and guides for urban air pollutants (World Health Organization 1972).

It is important to note that the epidemiological evidence upon which the numerical estimates of Table XIII are based were derived from studies of populations exposed to relatively uncontrolled fossil fuel combustion products, at a time when there were a number of major contributors to the unhealthy air environment. The major combustion sources included:

(1) smoke from domestic coal burning stoves, boilers, and open grates

(2) emissions from uncontrolled fossil-fueled power plants

(3) uncontrolled combustion products from boilers in factories, schools, incinerators, and other point sources

(4) products of uncontrolled automobile emissions

(5) localized emissions associated with specific industrial processes such as lead smelting, petrochemical refining, solvent use, etc.

These emission sources were often concentrated in urban areas, and their combustion products resulted in a visible blackening of

TABLE XIII

EXPECTED HEALTH EFFECTS OF SULFUR OXIDE/PARTICULATE AIR POLLUTION ON SELECTED POPULATION GROUPS*

Effect	Pollutant Concentrations (g/m^3)	
	SO_2	Smoke†
Excess mortality and hospital admissions	500 (0.17 ppm) (daily average)	500 (daily average)
Worsening of patients' pulmonary disease	250-500 (0.08-0.17 ppm) (daily average)	250 (daily average)
Respiratory symptoms and ventilatory function changes	100 (0.04 ppm) (annual arithmetic mean)	100 (annual arithmetic mean)
Visibility and/or human annoyance effects	80 (0.03 ppm) (annual geometric mean)	80 (annual geometric mean)

Definition of abbreviations: SO_2 = sulfur dioxide; ppm = parts per million.

*Source: World Health Organization 1972.

†British Standard Practice (Ministry of Technology 1966). See text for comparability with U.S. methods.

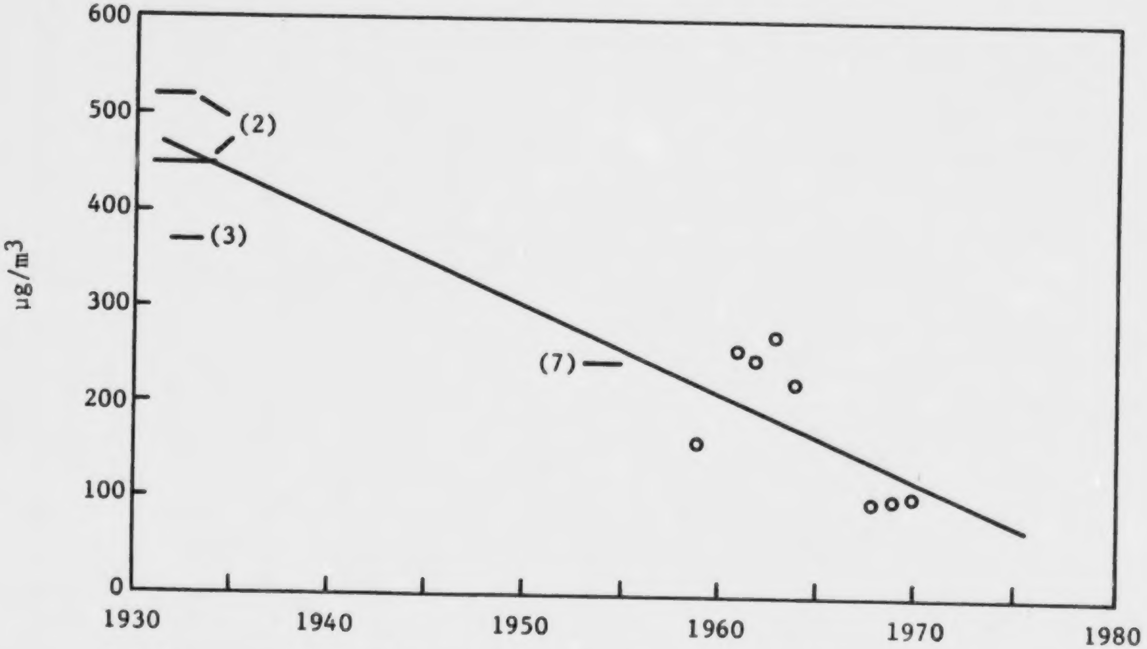
buildings, clothing, the atmosphere, and the lungs of the exposed population. It was impossible to determine whether one pollutant or a class of pollutants was solely responsible for the observed health effects. The quality and quantity of air pollutants in the urban environment undoubtedly varied greatly from place to place and from hour to hour, as a function of varying emission strengths, meteorological conditions and population mobility. Epidemiology studies were designed to demonstrate the extent to which excess disease and dysfunction could be reasonably attributed to the complex air environment, but it was not possible to specify which pollutant of the complex mixture was responsible for the observed effects. Epidemiologists relied on a few index pollutants, usually suspended particulate matter or smoke and SO_2, to characterize the air environment. No attempt was made to describe chemically the entire pollutant complex and there is no reason to believe that the unmeasured pollutants bore a constant relationship to the measured indices, SO_2 and particulate matter.

Since 1960, significant changes in emission sources have taken place. Homes are now heated by natural gas, oil, or electricity, and coal burning in homes has virtually disappeared. Power plants are equipped with electrostatic precipitators, or bag houses and tall stacks. Many power plants have shifted to low sulfur coal, oil, or natural gas. Since 1976, hydrocarbon and CO emissions from new automobiles have been reduced from 1970 levels by nearly 90 percent.

Many major industrial emission source categories have been regulated. These changes have been accompanied by a dramatic decline in atmospheric levels of SO_2 and particulates in many U.S. cities, as illustrated for New York City in Figure 10 for particulate matter and in Figure 11 for SO_2. Largely because of the switch from coal to oil, natural gas, and electricity for home heating, it is now possible to achieve more complete combustion of fossil fuels within cities, and this change has resulted in a 3-to 10-fold reduction between 1960 and 1975 in benzo(a)pyrene levels, which serve as an indicator of other polycyclic organic compounds related to the completeness of fuel combustion (Hoffman and Wynder 1977). Overall, these changes in emission sources have resulted in lower ambient concentrations of the sulfur oxide/particulate/BaP complex as measured by SO_2, total particulate, and BaP networks.

At the same time, there is evidence for increasing acidity in rainfall and in lakes of the Northeast and Midwest. These findings suggest changes in the ambient particulate mass that are not reflected in the usual measures of ambient air quality. Likewise, there is good reason to believe that the proportion of respirable particles is increasing, but little is known about the absolute amount of respirable particulate which would be much more important.

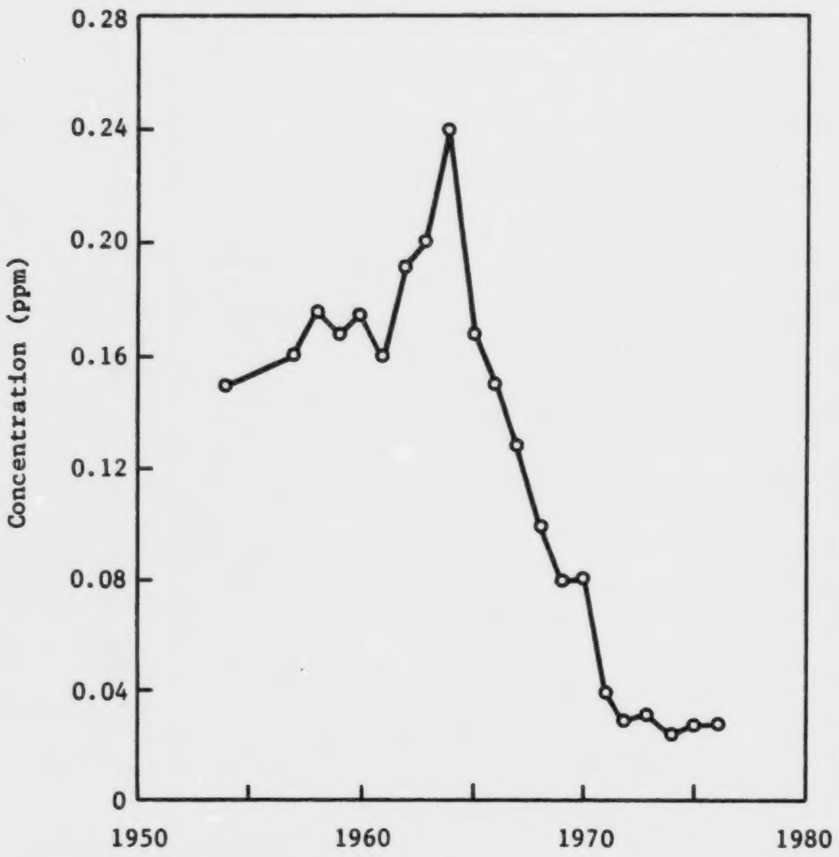
A number of undefined changes in organic aerosol emissions have also probably occurred and very likely are related to the changing use pattern of additives in gasoline, imperfect operation of



Total suspended particulates in New York City (1930-1976). Numbers in parenthesis refer to references. Data after 1955 are from reports of the New York Department of Air Resources. The sampling locations change from year to year.

Source: Eisenbud, 1978.

FIGURE 10
TOTAL SUSPENDED PARTICULATES IN NEW YORK CITY
(1930-1976)



New York Citywide annual average SO_2 concentration (1954-1976).

Source: Eisenbud, 1978

FIGURE 11
NEW YORK CITYWIDE ANNUAL AVERAGE SO_2 CONCENTRATION
(1954-1976)

catalytic mufflers, introduction of diesel engines in passenger cars, and introduction of new chemicals in the manufacture of industrial and consumer goods.

Thus, quantitative and qualitative changes in air quality have occurred since the 1950s and 1960s. These air quality changes are not well reflected in the usual indices of the sulfur oxide/particulate complex.

The generalized reduction in ambient particulate and sulfur oxide concentrations since the late 1960s has been accompanied by the virtual disappearance of recurrent and readily detectable lethal air pollution episodes in England. Likewise, differences in respiratory illness rates between more polluted and less polluted communities appear to have diminished considerably, to the point where some investigators claim that present levels of air pollution represent little or no health risk. Whether these claims are supported by recent epidemiological evidence is questionable, but there is general agreement that if the sulfur oxide/particulate complex is affecting health, these effects are less severe and less easily detectable than they were 15 to 20 years ago.

The burning of coal also produces solid waste materials that require disposal in environmentally compatible ways. The bulk of this residue is bottom ash formed by the nonvolatile mineral matter in the coal. In addition, to lessen the air pollution load, increasing amounts of flyash are being removed from the stack components by precipitators and other devices. About 70 million tons of bottom ash and flyash result annually in the U.S. from coal combustion (Wewerka et al. 1976). There is growing awareness that the discarded solid wastes from coal combustion may themselves be a serious source of environmental contamination as well as exposure to workers. In particular, these materials may be subjected to leaching by rain water or surface flows that could produce mineral or trace element contamination.

Energy-related water discharges from coal-fired power plants can be either continuous or intermittent. Continuous discharges include flows from cooling water systems and boiler blowdowns. Intermittent discharges include flows from boiler water pretreatment operations such as ion exchange, filtration, clarification, and evaporation. Other intermittent discharges include those from stack cleaning in which high pressure water is used to clean flyash and soot from stacks and cooling tower basins. The major water pollutants are likely to include suspended solids, metals, and other chemical wastes such as corrosion inhibitors and antifouling agents (Brown 1979).

Data on accidents associated with electrical power generation are sparse. Present Federal Power Commission (FPC) regulations require accidents to be reported to the FPC only when loss of power occurs. Thus, it is conceivable that an explosion in a boiler killing or injuring many workers will not be reported because an auxiliary boiler or generator took over and prevented a power outage.

Many state regulatory agencies have reporting requirements which are more strict than those for the Federal government (e.g., the New York State Public Service Commission).

Recommendations

1. The potential for causing effects to human health should be determined for solid waste residues from coal-fired boilers.
2. In light of the recent concern expressed by D. Costle of EPA over the potential health impacts from the radionuclides released as a result of burning coal, the health panel feels this problem should be examined in greater detail (U.S. EPA 1979).
3. Radioactive releases from disposed flyash should be examined.

4.3.2 Fluidized Bed Combustion (FBC)

The extent of occupational health hazards for personnel in and around FBC boilers will depend upon whether they operate at atmospheric pressure or are pressurized. The hazards may be expected to be similar to those for conventional pulverized coal combustors such as those from heat, noise, and coal dust. One difference is that the fluidized bed coal combustion processes use large quantities of pulverized limestone or dolomite to absorb SO_2. Limestone is considered a nuisance pollutant. However, it can act as a pulmonary irritant and excessive exposure may cause chronic bronchitis or emphysema (ACGIH 1976). Occupational exposure may be expected to result from transportation to, and storage at, the plant site and from stack particulate emissions. There is some indication that the use of impure limestone contaminated with quartz may also pose a threat of silicosis to the occupational population. Since the potential occupational hazards are due to conventional agents, there does not appear to be any special problem in measuring the exposures which occur.

SO_x and NO_x emissions are not expected to represent particular hazards from fluidized bed combustion and are expected to be within the standards set by EPA for coal-fired power plants (Brown 1979). However, carbon monoxide (CO) emissions are expected to exceed those from conventional coal-fired boilers because of the increase in temperature and decrease in excess air levels (Abelson 1977).

The identities of the trace organics emitted from the stack have not been well characterized since this technology is still developmental, it is also not known whether they pose particular health threats. Among the organics identified in one preliminary study (Murthy et al. 1978), the following species are known or suspected carcinogens: anthracene, methylanthracenes, pyrene, benzo(c)phenanthrene, benzofluoranthenes, and benzo(a)pyrene. Until the actual emissions are characterized and tested, however, the extent of the hazard is unknown. Available sampling and analytical techniques appear to be adequate for defining the extent of atmospheric emissions and ambient concentrations of the pollutants generated by FBC.

Solid wastes from fluidized bed combustion processes consist of spent sorbent (limestone or dolomite) and collected particulates from the particulate emissions control devices. These residues differ markedly in both chemical and physical properties from those of bottom ash and flyash from conventional coal-fired boilers and therefore, can be expected to have different biological properties (Abelson 1977). The amount of ash generated requiring disposal is also greater for FBC.

Spent sorbent contains large quantifies of calcium sulfate, unreacted calcium oxide, and if dolomite is used, magnesium oxide. Minor amounts of calcium sulfite and calcium sulfide may also be present. The solids may also be expected to contain trace metals: As, Be, Cd, Hg, Pb, Sb, Se, Te, Al, Fe, and Si (Abelson 1977). Some of these are known carcinogens, and for many trace metals excessive exposure may lead to toxic reactions.

Exposure to solid wastes can be expected to occur during disposal and through drinking water or food chain exposure should leaching occur.

Both EPA and DOE have programs to characterize the effluents and wastes both biologically and chemically from atmospheric pressurized fluidized bed combustion.

A serious accident can occur at a steam generating plant from explosion of the boiler. Pressurized FBC boilers operate at a combustion temperatures of approximately 1500°F (816°C) and pressures up to 10 atmospheres. Such pressures can present an explosion hazard.

The probability of explosion can be increased by the high dynamic stresses caused by high temperature and erosion in localized areas where temperatures may be greater than 1500°F (816°C).

Several additional but infrequent accidents can occur in the steam generating plant. Subatmospheric pressure in the condenser could cause an explosion, destroying the condenser. A tube rupture in the boiler can occur, leading to damage to the equipment as well as shutdown. A high-pressure, high-temperature steam line could rupture causing injury or death to nearby workers. Statistics on these accidents are not available.

The most severe accidents which may occur at a gas turbine plant are explosion, asphyxiation, and ruptured lines. Explosion, with possible subsequent fire, can occur in the turbine, compressor, combustor, and recuperator. In FBC gas turbine and steam plants, explosions may occur in the fluidized bed combustor system with ejection and dispersion of the bed contents. The containment vessel in an atmospheric fluidized bed system could rupture as a result of accidental pressurization, whereas pressurized vessels can suffer burn-through and explode. Both atmospheric and pressurized fluidized bed systems, fired with coal, also run the risk of fire from spontaneous combustion. In addition the fluidized bed coal combustor could release alkali metal hydroxides through leaks, pressure ruptures, error, or spilling. In the condensor or boiler an accident could occur which would result in an alkali-metal-water reaction causing fire explosion.

Recommendations

1. The extent of the thermal/combustion hazard from the exothermic reaction of lime in the ash from FBC and water should be determined.
2. Work place monitoring to determine levels of CO and other pollutants associated with FBC should be performed.
3. It should be determined whether limestone dust represents a workplace hazard in FBC. Silica contamination should also be considered.

4.3.3 Magnetohydrodynamics (MHD)

Magnetohydrodynamic combustion of coal is still in the experimental stage, though one or two pilot plants are being established. Occupational exposure to strong magnetic fields is likely to occur during MHD combustion of coal. The effects of chronic exposure to magnetic fields are not well known, but neurological, behavioral, and circulatory effects have been documented (Kleiner et al. 1975). Research is needed to define the potential exposure levels to the MHD magnetic fields because the technology is still largely experimental. Dose-response relationships between magnetic fields and physiological effects are not well characterized, and little U.S. research has been devoted to this area.

MHD combustion technology also introduces some other special occupational hazards which result from the use of potassium carbonate seed to produce the necessary electrical conductivity in the combustion products. The handling and injection of the seed and the regeneration of the seed can cause excessive occupational exposures. Seed regeneration involves the release of the sulfur captured by the seed, generally as H_2S.

Although the potential hazards from exposures to magnetic fields, noise, heat, and process leaks may be severe if proper engineering controls are not built in and maintained, the measurement technology available for monitoring the extent of the occupational exposures appears to be adequate.

Because of the developmental state of the MHD technology, characterization of the air emissions is far from complete. Most of the concern with MHD emissions has been directed toward those pollutants emitted from the stack. SO_x emissions are expected to be lower than those from conventional coal-fired power plants, but NO_x emissions are expected to be up to ten times higher due to the higher operating temperatures (Strom 1978). At the present time, the predicted MHD NO_x emissions exceed the National Primary Ambient Air Standard set by EPA (Strom 1978). For this reason major design efforts are underway to reduce the magnitude of NO_x emissions and hence the related health hazard.

MHD is also expected to result in more fine ($<2.5\mu$) particulates being released than from conventional coal combustion (Schmidt et al. 1976). This would increase the respiratory hazard since finer particles are more likely to be retained within the lungs.

Organic compounds are not expected to be a major problem with MHD since the higher temperatures will result in more complete combustion. Most of the organic compounds that are released will probably be adsorbed onto the surface of the particulates (U.S. DOE 1978).

Because potassium carbonate is used to seed the open-cycle MHD processes, flue gas releases can be expected to be contaminated to some degree with alkali salts despite recycling of the seed (Nader 1978). The magnitude of this potential problem and the exact nature of the effects resulting from chronic exposure are unknown.

Volatile trace metals can also be expected to occur as part of the air emissions from MHD processes. These would include Hg, As, Zn, Ba, Cd, V, and Se (Matray 1976).

The solid wastes resulting from MHD open processes can be expected to contain fewer heavy metals and trace organic compounds due to the high temperatures of combustion than the wastes from standard coal combustion techniques (U.S. DOE 1978). The potassium carbonate used to seed the reaction will, however, be present in increased amounts in the solid wastes, despite recycling (Matray 1976). When these solids are disposed, the leaching of the potassium alkalis and salts may result in an increase in salinity of local water supplies. It is not known whether this poses a threat to persons on restricted potassium intake diets.

Recommendations

1. The potential for exposure to magnetic fields and resulting health effects should be evaluated for MHD.
2. The potential for occupational injury from alkaline slags from MHD should be determined.
3. The potential for alkaline contamination of groundwater should be evaluated.

4.3.4 Coal-Oil Mixtures (COM)

The use of coal-oil mixtures in power plants will require facilities for comminution of the coal, mixing the finely divided coal with the oil, and storage of the mixture in sufficient volumes to assure a continuous supply to the boilers. The only operation that appears to introduce a potential occupational exposure problem different from those normally present in conventional coal- or oil-fired plants is the size reduction of the coal. The coal in the mixtures requires more crushing and grinding than in conventional powdered coal combustors. There will therefore be a greater potential for exposures to respirable coal dust and dust explosions. Diligent application of available exposure measurement and control technology should prevent excessive coal dust exposures.

Recommendations

1. The effects of catalytic trace metals from oil on the conversion of sulfur in coal to SO_3 and H_2SO_4 in the effluent air needs to be investigated.

4.3.5 Cocombustion with Municipal Solid Waste (MSW)

Because potentially pathogenic bacteria and viruses are present in municipal solid waste, the use of MSW in a coal-fired power facility will increase employee exposure to these organisms (Hall et al. 1979). Increased occupational exposures will occur mainly in the refuse receiving and classification areas. The occupational populations can also be exposed to aerosolized pathogens from the cofiring process (Diaz 1976).

A study of the pathogens in MSW indicates that a large portion of them are derived from animal rather than human wastes (Duckett 1978). Among the pathogens identified in MSW samples are Salmonella, streptococci, enteroviruses, and certain bateria and parasitic cysts. Although microbiological sampling techniques are difficult and seldom performed, they are available and can be used effectively.

The cofiring of coal and MSW is expected to result in increased atmospheric releases of Pb, Br, and Cl at levels which could exceed acceptable ambient exposure levels. The Br and Cl will result in acid formation which can be an inhalation hazard or result in acid rain damage to structures and vegetation. Other volatilized elements may be released in increased quantities over those from coal alone, but are not expected to result in excessive exposures. These include: Sb, As, Cd, Hg, and F.

The cofiring of coal and MSW also results in the release of complex organics, bacteria, and viruses. The emission controls used for the cofired boilers will usually be less efficient than those in a conventional coal-fired plant, resulting in increased emissions per Btu.

The concentrations of the elements Br and Ba are expected to increase in the bottom ash and flyash resulting from cofiring of coal and refuse derived fuel (RDF) and may, under certain conditions, result in adverse health effects. Bromine containing compounds may be strong irritants and can, in sufficient quantities, cause lung damage (Britt and Hushon 1976). Barium may increase the salinity of ground water if leaching occurs and might pose a threat to persons on restricted sodium intake diets.

Other trace elements which occur in higher concentrations in RDF than in coal and which are expected to increase in the bottom ash and flyash are: Cd, Cr, Cu, Ti, and Zn. Releases of these metals are not expected to occur at levels which would pose a threat to human health should leaching occur from solid waste disposal sites (Fiscus 1977).

Recommendations

1. Evaluate effects of occupational exposure to increased pathogen levels associated with cofiring of RDF and coal.
2. Evaluate exposures to cadmium and chlorinated hydrocarbons as a result of cofiring of RDF and coal.

5.0 EPIDEMIOLOGICAL STUDIES

5.1 Introduction

In assessing the human health consequences of the various coal-based energy technologies, epidemiological studies provide a fundamental means for obtaining insight into the relationship between the actual complex human environment and the resulting risk of human disease. Using appropriate measurements of exposure, disease, and extraneous risk factors, the epidemiologist can identify whether excess disease or dysfunction can be reasonably attributed to a specific energy-related, occupational, or community environment.

The strengths and limitations of the epidemiological approach need to be appreciated. An overriding strength is the ability to make observations on actual exposures of population groups and to relate these exposures directly to disease or dysfunction in humans. To make a valid association between environmental or occupational exposure and disease, the epidemiologist must simultaneously assess the potential contribution of other risk factors for the disease of interest. While it is often difficult to account for all pertinent risk factors, the epidemiologist can and must determine the distribution of major risk factors in his study population and demonstrate that he is effectively adjusting for the possible effects of these extraneous factors. Too frequently, information on important extraneous risk factors is not obtained, but this deficiency simply reflects the inadequacy of the epidemiological design and is not an inherent limitation to the epidemiological approach.

The disadvantage of even well-designed epidemiological studies of occupational and community environments is the limited ability of the epidemiologist, or of anyone else, to characterize the complex environment to which humans are exposed. With few exceptions, it is not feasible to determine that one component of a complex environment is responsible for observed health effects, and only a few well-established indices of environmental exposure can be utilized in most epidemiological investigations. These indices are useful in demonstrating that there is a difference in exposure between two or more population groups, but it is rarely possible to use these indices to obtain integrated dose estimates of individual exposures or to determine whether the index pollutant is necessarily the "causal" agent responsible for disease excess. Thus, epidemiological studies seldom can be used to partition the effects of one environmental component from another and rarely can be used to arrive at replicable dose-response relationships.

Nevertheless, epidemiological evidence can be used together with experimental results derived from pollutant-specific studies to evaluate whether disease excess can be attributed to a certain occupational or community environment, and to judge whether this disease excess, if observed, is most likely to be associated with a suspected, hazardous component of that environment. For example, epidemiological studies have shown that occupational groups exposed to asbestos, uranium ores in underground mines, or bis-chloromethyl ether are at greater risk of lung cancer. Such evidence can serve as a basis for intervening in the work environment. Likewise, epidemiological studies can be designed to follow population groups exposed to a new environment produced by an energy technology, and conclusions can be drawn from these studies concerning differences in acute or chronic disease risk between exposed and control or reference populations. There is no substitute method to obtain such information.

Recommendations:

1. Retrospective cohort mortality and case-control studies, specific for cause of death, should be conducted on coal mining groups to evaluate relationships of mortality with type of mining experience and with disability experience of coal miners. Tobacco use and other extraneous risk factors need to be considered for these groups.

2. The risks of coal workers' pneumoconiosis and chronic obstructive lung diseases need to be related to coal mine dust levels, with control for other risk factors and considering the possibility of enhancement of risk by ethnicity, tobacco, or other modifiers of disease risk.

3. Epidemiological studies on the frequency of, and risk factors for, hearing disorders among coal miners should be conducted, including the contribution of occupationally related noise to accident potential in coal mining. Similar assessments of vibration effects should be made.

4. Epidemiological studies should be conducted to compare health and pertinent functional effects in coal miners exposed to diesel or to electric-powered vehicles underground. Studies should include an assessment of pulmonary effects, noise, vibration, and heat.

5. More extensive epidemiological studies of surface miners are needed.

6. The adequacy of heat-stress standards and practices in underground mining should be studied by epidemiological methods.

7. Reproductive effects of the working environment associated with various coal-based energy technologies need to be evaluated. Attention should be given to effects on both working women and men including effects on fertility patterns, reproductive organs, and other target tissues subject to estrogenic or androgenic influences.

8. The possible accumulation of trace metals related to coal-based energy technologies should be studied in occupationally exposed groups and in communities located near energy sources. The potential interactions of such heavy metals as cadmium and lead with essential body minerals such as copper and zinc should be examined in terms of cardiovascular disease in humans.

9. The reported excess of gastrointestinal cancers among coal workers should be evaluated, with due consideration given to oral tobacco use, ethnicity, and other known risk factors. Similar studies might be conducted in communities located near coal-based energy facilities.

10. Prospective studies are needed of workers exposed to emissions and other byproducts related to advanced coal technologies. Similar studies should be instituted in communities adjacent to these facilities.

11. In situ gasification poses a risk of worker exposure to vented gas streams. Epidemiological studies of these occupational groups should be initiated.

12. The potential effects of worker exposure to microorganisms and to antibacterial disinfectants at coal cocombustion with municipal solid waste facilities should be evaluated.

5.2 Epidemiological Assessment of Community Exposure for the Expanded Use of Coal Technologies

Increased use of coal in the 1980's does not imply a reversion to the polluted ambient air conditions of the 1940s and 1950s. Coal will not be burned in uncontrolled home boilers and fireplaces but in processes that will achieve very efficient combustion and considerable removal of sulfur from the gas stream. The resulting air emissions will be quantitatively different from the particulate and organic complex of sulfur oxides that was associated with adverse health effects previously described.

Epidemiological studies can be designed to address the question whether the complex air environment created by new coal technologies is a risk factor for adverse health effects. In conducting these studies, the epidemiologist must be able to contrast population groups exposed to different air environments. If excess disease or dysfunction can be attributed to one of the air environments, while controlling for extraneous risk factors and other sources of bias, it is possible to conclude that the air environment probably is adverse to health. Replication of these results for other populations similarly exposed strengthens the argument.

However, the most difficult component of these studies is the characterization of population or individual exposure to air pollution. To evaluate the newer coal-based technologies, exposure cannot be adequately assessed in terms of the usual indices of air quality especially when these indices are derived from stationary outdoor monitors of SO_2 and total particulates alone. Additional factors in the air environment that need to be considered include:

- transformation products of SO_2
- respirable or inhaled particulates

- organic aerosols
- indoor sources of pollution

While it is undoubtedly true that all four of these environmental factors previously contributed to population exposures in the 1950s and 1960s, the indices of SO_2 and total particulates were generally thought to be adequate to classify population exposure to ambient pollution. The significant decline in SO_2 and total particulate levels during the 1970s makes it much more difficult to characterize differences in individual exposure without making specific assessment of respirable particulates and indoor exposure, in addition to the other factors mentioned above.

With reduction in ambient particulates, it is particularly important to evaluate indoor sources of particulate exposure. In ascribing the exposure of all residents of a community to the average value recorded by a stationary outdoor particulate monitor, the epidemiologist will invariably misclassify exposure status for many study participants. In an apparently "exposed" community, a number of persons will spend a considerable portion of their time in a relatively clean home or office environment, while others in the same community will be more exposed to both outdoor and indoor sources of particulates. A similar potential for misclassification exists in the "unexposed" or control communities. If diseased and nondiseased individuals in each study community are equally misclassified, any estimate of an effect of air pollution on health status will be systematically biased towards the null hypothesis of no association.

It is now possible to monitor personal exposure to air pollutants, and to assess respirable particulate concentrations. These improved methods need to be incorporated into epidemiological studies designed to evaluate the impact of the newer coal-based technologies. Unfortunately, direct measurements of organic aerosols or of atmospheric transformation products of SO_2 have not been developed for population studies. However, it may be possible to develop surrogate measures of exposure to organic aerosols based upon the proximity of study groups to organic emission sources. These surrogate measures could be validated by appropriate chemical analyses of air samples, but considerable exploratory research is required on this issue. Differences in population exposure to atmospheric transformation products of SO_2 also require exploratory studies.

Related to these exposure assessments is the need to determine to what extent the newer coal-based technologies will contribute to generalized or local population exposure to organic aerosols, respirable particulates, transformation products of SO_2 (or NO_2), and to acid aerosols. Disease risk is expected to be proportional to population exposure to these factors, though some emissions byproducts are likely to be of more concern than others.

Recommendations:

1. Prospective community-based studies of populations in the vicinity of advanced coal-based energy facilities should be instituted. These studies should incorporate environmental assessments related to exposure to inhalable particulates, indoor sources of pollutants, and, where pertinent, assessments of exposure to organic aerosols.

2. Epidemiological studies are needed to determine whether the air environment characterized by the generally lower air pollution concentrations found in the 1970s continues to pose a public health hazard. In these studies, newer indices of inhalable particulates, aerosol acidity, and possibly organics should be evaluated and, where appropriate, utilized. Likewise, individual exposure to indoor sources of pollution, as well as to extraneous risk factors, must be carefully evaluated in these studies.

See recommendation 3 in section 6.3.1.

5.3 Evaluation of Carcinogenic Risk to Populations

Assuming that a variety of laboratory methods will be utilized to assess carcinogenicity, the carcinogenic risk to populations associated with coal-based technologies should also be directly studied by epidemiological methods. The long latency for development of most chemically caused cancers will probably prevent investigators from arriving at firm conclusions within a decade, thus considerable thought will have to be given to the selection of study populations and to measures of carcinogenic exposure. The possibility that early biological markers of cancer risk might be utilized should be considered as a means of bridging the latency problem.

Recommendations:

1. Since coal emission products are known to contain a number of potential carcinogens, the issue of population exposure and methods to evaluate carcinogenic response of populations to exposure to these products should be addressed nationally through symposia, interagency task groups, the National Academy of Sciences, or other approaches. Baseline data on exposed and control populations should be acquired in the near future, and thus it is desirable to address the complex aspects of study design in the near future.

6.0 EXPERIMENTAL STUDIES

6.1 Pulmonary Effects

6.1.1 Introduction

The lung is the first organ to encounter airborne agents resulting from coal production and utilization. Both occupational and general populations are exposed to substances such as polycyclic aromatic hydrocarbons, heavy metals, radionuclides, and halides which occur in both gaseous and particulate forms. Some compounds enter the lung and cause local or general pulmonary toxicity; others enter via the lung and exert their toxic action elsewhere.

Contact of inhaled vapors with the surface of the respiratory tract is governed by laws of diffusion. Subsequent behavior of vapors is dependent on the physical and chemical properties of the specific gas or vapor. Deposition of particulates in various lung compartments is a function of breathing kinetics and the size of the particle. The three major deposition mechanisms are impaction, sedimentation, and diffusion. The importance of these mechanisms is a function of particle size with large (>3 μm) particles depositing primarily by impaction and very small (<0.5 μm) particles depositing by diffusion.

Soluble particles will rapidly dissolve in the mucus and enter the internal milieu where the chemical nature of the material governs its subsequent behavior. Insoluble particles deposited in the upper regions of the respiratory tract (nasopharyngeal and tracheobronchial regions) are usually removed by the ciliated epithelium (mucociliary escalator) relatively quickly and expectorated or ingested. Particles reaching the alveoli can be absorbed into the bloodstream or be phagocytized by the alveolar or interstitial macrophages. Alveolar macrophages are thought to end up on the mucociliary escalator, whereas interstitial macrophages are thought to enter the lymphatic system and deposit material in regional lymph nodes. Inhalation of large numbers of particles can overwhelm the macrophage response resulting in formation of granulomatous-like lesions.

The assessment of toxicity of air pollutant mixtures, water pollutants, complex liquids, etc., is difficult. One approach is to consider individual components of the mixture singly and then begin to add them together in order to see if the toxicity of the mixture is different from those of the individual agents. The antithesis of the above is to conduct animal studies on complex mixtures found in the environment. An obvious shortcoming of this approach is the difficulty of simulating the atmospheres that are encountered in the environment. This approach also suffers from the fact that the pollutant concentrations are usually low, often leading to negative results. Negative results are difficult to interpret because of the low doses used, the limited number of animals employed in the study, and species specificity. Furthermore, if positive results are observed, it is not possible to distinguish the causative agent(s).

A second major dilemma in assessing toxicity is what concentrations of agents to study. Toxicologists, in evaluating health effects, often expose animals to concentrations of compounds that are several orders of magnitude over what may be encountered in the environment. They justify this approach on the basis that they need to observe some response, that they can only test a limited number of animals, and that the test species may be less sensitive than man to the particular agent. This approach is criticized on the basis that the response at high concentrations may be entirely different from that at more normal concentrations.

The idea of performing animal studies at ambient concentrations, however, is equally disturbing, since in most cases it is unlikely that positive health effects will be observed. Negative studies in animals should not be construed as evidence that an agent or mixture is harmless.

Mention of these two controversies, single compounds vs. mixtures and high vs. low doses, is necessary to point out that one approach by itself will not address all of the issues. Research should be carried out using all the approaches, and the results integrated in order to give a comprehensive picture of the health effects of coal-related pollutants.

Recommendations:

1. Continuation of research investigating the basic nature and function of the respiratory system is recommended. The committee recognizes that this is not a specific task; however, it wishes to emphasize that this type of research

deserves continued support. The protective mechanisms of the respiratory tract need to be better characterized. Pulmonary biochemical processes such as collagen deposition, biochemical buffering, secretory functions, enzyme reactions, and immunologic interactions need to be further elucidated. Further research is needed on pulmonary deposition and clearance; the mechanisms of clearance require deeper understanding. The role of the pulmonary macrophage in many of the above-mentioned processes is of great interest. Finally, there is a great need to develop more sensitive indices of impaired pulmonary function in both man and experimental animals.

2. Studies have implicated that SO2 and NO2 when given in combination with benzo(a)pyrene cause a higher incidence of tumors than benzo(a)pyrene only. Further elucidation of the role of oxidants, NO_2 in particular, and SO2, in carcinogenesis is required.

3. The pulmonary carcinogenicity of specific coal-related pollutants should be determined once these agents are identified as probable pollutants.

4. The increased use of coal in all of these processes could result in increasing amounts of SO_2 emissions thereby increasing production of secondary sulfate aerosols. Animal and human studies are needed to compare the toxicity of the various species of acid sulfate aerosols.

5. Inhalation studies are needed to assess transient effects of inhalation of ambient levels of coal-related pollutants on both healthy and diseased individuals.

6. Human tissues should be analyzed for organic and trace metal constituents which may be there as a result of exposure to coal related effluents.

7. Investigation of fine particles as vehicles for transport of carcinogens to target lung tissues needs to be performed.

8. More research is needed to determine the optimal strategy for testing the pulmonary effects of mixtures of pollutants.

6.1.2 Process-Specific Problems

6.1.2.1 Conventional Coal. The mining of coal is a dirty process long recognized as responsible for a variety of diseases collectively referred to as black lung disease. Coal is mined underground and in surface mines; however, underground mining produces a higher incidence of pulmonary disease than surface mining. In underground mining the substances of most concern are coal dust, silica dust, methane, some volatile hydrocarbons, and, in some mines, diesel engine exhaust emissions. The miners themselves are the population at risk. In surface mines, dust is the major environmental factor and in addition to the miners, the population at large is also at risk; however, the impact on society is reduced since most mines are located in sparsely populated areas.

During the mining of coal, the miners are exposed to all of the various organic and inorganic constituents of the coal and the surrounding strata. The concentration of inorganic elements, primarily trace metals, varies widely. Only a few of the several thousand hydrocarbons present in coal and coal tars have been identified, and fewer still have been characterized with respect to biological activity. In addition to producing direct toxic effects, some of the hydrocarbons can escape into the atmosphere and react photochemically to produce aldehydes which are potent irritants. These aldehydes can then be absorbed by particles and react at different sites in the lung in a manner different from their action as gases.

About 25 percent of raw coal is comprised of impurities which can be removed by physical cleaning. These processes are generally wet processes and as such probably do not present additional pulmonary problems. Crushing raw coal mechanically using dry processes produces more fugitive dust; however, most of these processes can be run under wet conditions as well. This may also cause an environmental impact in the form of leachates.

The distance from the mine mouth to the site of combustion can have a direct impact on the amounts of pollutants released to the atmosphere. Trains and trucks can disperse fugitive dusts from the coal being transported. Engine exhaust emissions from locomotives and trucks can be significant, especially on long runs.

Combustion of coal produces oxides of sulfur and nitrogen, CO, CO_2, and flyash. Flyash usually contains the following trace metals as oxides, sulfur oxides, or carbonates: As, Be, Cd, Co, Cr, Cu, Fe, Ni, Pb, Se, and V (Brown, 1979). There are also some emissions of mercury vapor, hydrocarbons, polycyclic aromatic hydrocarbons, and organometallics. Within the atmosphere, a major mass fraction of the airborne particles is formed from oxidation products of sulfur dioxide, e.g., H_2SO_4 and its ammonium neutralization salts.

Pulmonary deposition of many of the agents resulting from coal mining singly and in combination can produce physiologic and toxic effects on the lung and in other organs. Many of the trace metals and some of the organics have been identified as possible causative agents in lung cancer. Clinical evidence supports the notion that ambient levels of various coal combustion products such as particulate oxides cause irritation of the bronchial airways, pulmonary parenchyma, exacerbation of asthmatic conditions, and a decrease in ventilatory function (Goldstein 1977).

Recommendations:

1. Clinical studies on coal miners are necessary to better characterize and describe the degree of impairment, to develop more sensitive and earlier indices of coal workers' pneumoconiosis, and to determine when, if ever, the initial changes produced by coal dust are reversible.
2. Coal workers' pneumoconiosis has been observed more frequently in miners in Appalachia than in miners from Western coal deposits. Animal studies should be performed in an attempt to amplify and explain this observation.
3. There is a need to develop an animal model of coal workers' pneumoconiosis (CWP) in order to: 1) define the processes resulting in CWP and see if they can be interrupted or reversed, 2) determine which constituents of the mine dust are responsible for the CWP (silicates, coal dust, beryllium, etc.), and 3) study deposition, clearance, and biochemical interaction as a function of the degree of pneumoconiosis.
4. Since use of diesel engines in mines is increasing, inhalation toxicology studies are needed to assess health effects of reaction products of diesel exhaust emissions and other mine air pollutants.
5. Variations in the composition and other characteristics of respirable dust from different coal seams should be studied because it has been demonstrated that factors other than concentration significantly affect the incidence of coal workers' pneumoconiosis.

6.1.2.2 Chemical Coal Cleaning. These processes are, for the most part, developed to the laboratory or bench scale. The majority of these are closed loops that recycle many of the chemical intermediates. However, there are always fugitive emissions. Disposal of the waste products poses the primary problem.

Several proposed processes present particular pulmonary problems. The Magnex process uses iron carbonyl to coat coal for magnetic separation. Both CO and $Fe(CO)_5$ are used throughout the process and special efforts to contain these gases are necessary. The Meyers process is a complicated process that at one point could release SO_2 to the atmosphere from a vent gas scrubber. The GE process produces large amounts of H_2S that are further processed to produce sulfur. The JPL process uses a chlorination-dechlorination process to remove both pyritic and organic sulfur. Trichloroethylene (TCE) will be used in the process which has the potential to release TCE, HCl, Cl_2 and other halogenated hydrocarbons. NO_2 is a potential pollutant in the KVB process in which coal is heated with NO_2 to convert sulfur to SO_2 and soluble sulfates. Virtually all coal cleaning requires coal storage, some sort of size reduction and sizing, and most require some further treatment such as blending or slurrying followed by reacting the coal in a pressure vessel. The initial steps of all the processes are such that coal dusts and other particulates are likely to enter the atmosphere. However, the problems do not seem unique to this technology. The most important problem appears to be emission of a variety of gases including CO, NO_x, H_2S, NH_3, SO_2 and/or metal carbonyls subsequent to the high pressure and temperature reactions.

Recommendations:

1. The chronic toxicity of metal carbonyls such as nickel, iron, and cobalt carbonyls should be investigated in rodents with emphasis on the mode of interaction and the role of the action.

6.1.2.3 In Situ Gasification. The in situ conversion processes are largely untried at the commercial level. Thus, although a number of pollutants have been identified, the nature of their interaction with the environment cannot be predicted. The research to date is not sufficient to delineate the potential impact of in situ gasification on the environment, resulting, therefore, in adverse pulmonary effects.

Recommendations:

1. Research is needed to define the product gas from in situ gasification, to determine the combustion products of that gas, and to assess the toxicity of both.

6.1.2.4 Fluidized Bed Combustion. The major impact on air quality due to FBC from the stack emission of both gaseous and particulate combustion products requires research to prevent hazards to the pulmonary tract.

Recommendations:

1. Comparative toxicity studies should be performed to see if limestone as used in fluidized bed combustion by itself or in association with coal dust presents unusual inhalation problems.

2. Stack emissions from fluidized bed combustion should be assayed for toxicity, mutagenicity, and carcinogenicity.

3. Evidence suggests that flyash from FBC may be different from the spherical glassy flyash as described by Fisher. Health effects of this irregular material should be characterized.

4. The effects of inhaled particles from FBC in association with, or coated with, alkali salts should be studied.

6.1.2.5 Magnetohydrodynamics. Plants using MHD technology are expected to generate pollutants similar to other direct combustion processes. However, because of higher efficiency, the amounts of pollutants and their environmental impact are expected to be less than those from conventional generation stations with similar megawatt outputs.

6.1.2.6 Coal-Oil Mixtures. The nature of the pollutants from COM technology are expected to be the same as those from conventional handling of coal and oil.

Recommendations:

See recommendations in section 6.1.2.1.

6.1.2.7 Cocombustion with Municipal Solid Waste. The use of this technology presents the possibility for viral exposure since tests show that municipal solid waste contains some human and animal excreta. Trace element emissions increase, and chloride emissions are proportional to the amount of refuse-derived fuel (RDF) burned.

Recommendations:

1. There is a need to assess effects on workers from inhaling increased numbers of bacteria and viral agents as well as the antibacterial disinfectant used at municipal solid waste facilities.

2. Some research is required to determine the impact of increased chloride emissions from this technology.

6.2 Skin Effects

6.2.1 Introduction

The skin, as the interface between man and his environment, is a portal for both entry and excretion of hazardous substances and a target organ for damage by physical, chemical, and biological agents. Exposure is primarily a problem of occupational employees; the general population receiving only limited dermal exposure.

Despite the fact that the skin is endowed with a versatile group of defenses, skin-related illnesses comprise 35 to 85 percent of occupationally related diseases (Suskind and Majeti 1976). Patterns of adverse effects range in quality from uncomplicated itching to metastatic neoplasia. Most adverse cutaneous reactions are eczematous including ulceration and granuloma formation and result usually from exposure to primary irritants. Other effects include allergic reactions such as immediate hypersensitivity and cell-mediated response (contact dermatitis), photosensitivity both phototoxic and photoallergic, pilosebaceous reactions like acne and damage to hair or hair follicles, sweat gland reactions such as miliria, pigment reactions, and cancer.

Absorption of chemicals across the skin has received relatively little attention compared to pulmonary absorption for compounds soluble in both water and nonpolar solvents. Quantitative information on skin absorption in man of most chemicals of importance as occupational and environmental hazards is usually lacking.

In the following sections, conventional coal and advanced coal technologies will be considered with regard to dermal exposure.

Recommendations:

1. Studies should be undertaken on the structural (cellular) and biochemical characteristics of nonallergic inflammation reactions (primary irritation) and to determine differences in pathophysiological patterns as influenced by molecular characteristics of the irritant, the rates of penetration, metabolism of the irritant, lysosomal and kinase activity, etc. Efforts should be focused on the ubiquitous marginal irritants.

2. Modern skills of immunobiology and immunochemistry should be applied to the elucidation of mechanisms of allergic cutaneous responses, particularly the contact type. Substances such as the transition metals, aldehydes, alcohols, phenols, and ketones should be studied in depth. Critical aspects requiring examination are the role of molecular structure, metabolism by mammals, protein-combining characteristics, effect of macrophages, lymphocytes, etc., as well as interferences or enhancement of sensitizers by other environmental agents.

3. More sensitive methods should be developed for predicting adverse responses to primary irritants, especially those of a marginal nature, to acnegenic substances, and to chemical and physical agents or combinations of those which induce pigment changes.

4. With the array of tests available for predicting allergenicity, a serious attempt should be made to compare the sensitivity and reliability of these tests in relation to clinical experience.

5. Basic studies should elucidate the factors determining skin permeability to chemicals. Our current knowledge on skin permeability depends heavily on a limited number of publications from experiments carried out over 30 years ago. The effects of physical factors such as temperature, humidity, and pressure in mines on the rate of absorption and length of retention of chemicals need to be better understood.

6.2.2 Process-Specific Problems

6.2.2.1 Conventional Coal. Exposure of skin to liquid, gaseous, or solid pollutants may occur at several stages during the conventional coal technology cycle from mining through combustion. During mining workers are exposed to large quantities of coal dust of various composition, depending on the location of the coal seam. Coal dust is not considered to be an active agent affecting the skin.

During the coking process, workers may be exposed to many complex substances. The constituents are usually divided into three categories: total suspended particulates, benzene-soluble organics, and polynuclear aromatic hydrocarbons.

Distillation of coal tar produces coal tar pitch, creosote, and other chemicals and oils. Coal tars have been shown to produce both skin cancer and acneiform lesions in coke oven workers in addition to observable increases in lung, bladder, and scrotal cancer. The highest worker exposure occurs during cleaning and maintenance operations, since the tars tend to build up on the surfaces of the scrubbers. Workers may also be exposed to dusts during disposal of the slags, ash, and other coal solid wastes remaining after combustion. These dusts contain some potentially toxic organics and trace elements.

Recommendations:

1. Information is needed to determine the frequency of dermal effects among exposed workers. To accomplish this, searches for dermal lesions should be included as part of regular medical screening, especially for coke oven workers.

2. The potential for the photoactivation of coal dusts and coal tar products should be investigated.

3. Agents which facilitate or suppress skin absorption should be identified and methods of removing skin contamination, once it occurs, should be studied. Data are needed on the use of blocking creams to reduce exposure to PAHs and on how well they function in a real work environment as opposed to laboratory simulations. The development of new, more effective blocking creams is needed.

6.2.2.2 Chemical Coal Cleaning. Compared to conventional coal technology, except in a few cases, chemical coal cleaning should not lead to unusual exposures of the skin. The PETC and JPL technologies will lead to the generation of acid mists, and the Battelle and Ames methods may lead to exposure of skin to irritating caustic alkaline materials.

Recommendations:

See recommendations 1, 2 and 3 in Section 6.2.2.

6.2.2.3 In Situ Gasification might lead to occupational exposures of the skin to a wide variety of organic and inorganic chemicals. These include primary irritants such as ammonia, chemicals having the potential for allergic reactions such as the thiocyanates, and chemical carcinogens such as PNAs.

Recommendations:

1. The mutagenic and carcinogenic properties of new organic chemicals produced by in situ gasification should be systematically and carefully assessed before the processes are accelerated to full scale production.

6.2.2.4 Fluidized Bed Combustion should not lead to specific skin exposure problems.

6.2.2.5 Magnetohydrodynamics may lead to irritation of the skin in workers exposed to alkali salts.

Recommendations:

See recommendations 1, 2 and 3 in Setion 6.2.2.

6.2.2.6 Cocombustion with Municipal Solid Waste. This technology should not lead to serious problems of skin exposure.

Recommendations:

1. The effects of exposure of the skin of workers to bacteria and viruses form MSW should be determined.

6.2.2.7 Coal-Oil Mixtures. Dermal exposure to dust may occur during combustion of coal-oil mixtures, but this should not pose any unusual problems.

6.3 Gastrointestinal Effects

6.3.1 Introduction

As in the case of skin and lung, the gastrointestinal tract is both a portal for entry and excretion as well as a potential target for physical and chemical agents. Aside from clearance of the respiratory tract with subsequent ingestion, sources of gastrointestinal exposure to coal process pollutants in the occupational environment are believed to be negligible. The general population, however, may be exposed via ingestion of contaminated drinking water, food, and nonfood items.

Ingestion exposure can occur through a number of ways. Various trace metals, organics, and radionuclides from combustion stack emissions may be deposited on soil and vegetative surfaces. Leachates from coal stockpiles, mines, and combustion wastes enter both surface water and groundwater supplies and may, therefore, enter drinking water. In addition, nonfood sources ingested through normal hand-to-mouth activity, especially in children, can contain high concentrations of various deposited pollutants. For example, lead in dirt/dust samples has been recorded as 2.4 mg/g in some areas (Hunt et al. 1971).

Absorption rates in the gastrointestinal tract for various pollutants are dependent upon the physical and chemical characteristics of the pollutants, their binding characteristics within bulk foods, and their solubility (lipid and water). Although coal-related pollutants (e.g., trace metals) are not usually present in toxic concentrations in food and water, the addition to the total cumulative uptake from all sources can initiate clinical effects (e.g., lead, arsenic, mercury, cadmium).

Recommendations:

1. Animal models for human gastrointestinal exposure to coal-related pollutants should be designed to provide insight into the biochemical, physiologic, and cellular events which occur intraluminally and within the tissues of the tract. Once obtained, such insight will provide a rational basis for preventive measures.
2. Sensitive tests for detecting early damage to the human alimentary tract by coal-related pollutants should be developed. Such tests may also provide essential data on related biochemical, metabolic, and pathophysiological mechanisms.

3. Epidemiological studies are needed to determine the frequency and gravity of gastrointestinal effects.

4. The absorption and distribution rates from the gastrointestinal tract should be determined for any pollutants found to have major uptake from this route.

5. Most large particles end up in the gut after mucociliary clearance from the respiratory tract. There is a need to better define the particulate absorption from the gut and direct particle transfer through the gut wall.

6. Work is also needed to identify metabolites for those pollutants analyzed as representing the most significant human health hazards.

6.3.2 Process-Specific Problems

6.3.2.1 Conventional Coal. Gastrointestinal exposures to coal-derived pollutants in the occupational environment may be negligible; however, oral diseases (gingivitis, leukoplakia, edema of the oral mucosa) have been reported. Occupational and general populations may be exposed by ingestion of contaminated drinking water, food, and nonfood materials.

Recommendations:

1. Food contaminant monitoring activities should be expanded to provide data on additional categories of contaminants. Coal-related pollutants in drinking water should be identified in a few key locations near coal mines, coal-fired power plants, and coal waste disposal sites.

2. Studies are needed to determine the cause(s) of excesses in the incidence of stomach cancer observed among coal miners.

See recommendations 1 through 6 in Section 6.3.1.

6.3.2.2 Chemical Coal Cleaning. This process should not produce effects on the gastrointestinal tract in addition to those already discussed for conventional coal.

6.3.2.3 In Situ Gasification. In situ gasification may result in water emissions of soluble metals, phenols, indoles, quinolines, and pyridines with a potential for gastrointestinal absorption. These may be transported through aquatic food chains or be present in drinking water derived from groundwater sources.

Recommendations:

1. Studies are needed on the chemical forms of metals in water; the binding to sediments and chemical transformation by micro-organisms or by chemical processes.
2. The stability and chemical transformations of organic substances in water require further study.
3. Further information is needed on the accumulation of metals and related organometallic compounds in edible fish, their biological half-lives in fish, and the resulting metabolic products.
4. Information is needed on the efficiency of gastrointestinal adsorption in man of metals and coal-related organic pollutants.
5. Studies should be made on the changes in intestinal microflora in man induced by metals and coal related organic pollutants. Tests should be made to see if intestinal microflora in humans metabolize metals and coal-related organic pollutants and if such metabolism modifies the intestinal adsorption and toxicity of these substances.

6.3.2.4 Fluidized Bed Combustion. This technology may lead to the loss of trace metals from solid waste with a potential for accumulation in food chains leading to man.

Recommendations:

See recommendations 1 through 4 in section 6.3.2.3.

6.3.2.5 Magnetohydrodynamics. Trace metals may be lost from solid wastes from MHD. These may accumulate in food chains resulting eventually in human exposure.

Recommendations:

See recommendations 1 through 4 in section 6.3.2.3.

6.3.2.6 Cocombustion with Municipal Solid Waste. The possibility of infectious agents, e.g., Salmonella, enteroviruses, entering the gastric system must be considered as a result of increased use of this technology.

Recommendations:

1. Factors governing human susceptibility to Salmonella and enteroviruses need to be investigated. Current theraputic procedures should be reviewed with the objecive of improving the effectivness of these methods.

6.3.2.7 Coal-Oil Mixtures should not present a special hazard to the gastrointestinal tract.

6.4 Behavioral and Neurotoxic Effects

6.4.1 Introduction

Human behavior can be affected by exposure to a wide variety of chemicals including heavy metals, organic solvents, and noxious gases such as carbon monoxide. Since conventional coal mining, and combustion, and the wide array of advanced coal technologies under consideration in this report may result in worker exposure to many of these substances both singly and in complex mixtures, the potential for development of behavioral and neurotoxic effects must be evaluated for each process.

It first may be worth setting out the type of information that is desirable as a background for decision making when the concern is the behavioral effects of a chemical. It is certainly desirable to know whether a chemical changes the ability of an organism to see, hear, taste, smell, or feel, to maintain its equilibrium, to move its limbs in a coordinated fashion without tremor or any other evidence of lack of control, to feed itself, to find a mate and indulge in appropriate sexual behavior and infant rearing, to maintain its place in its ecological niche and defend itself against aggressors, to communicate in appropriate ways, and to respond to its environment and the contingencies of reinforcement therein successfully. This short and incomplete list shows the complexity of the task of ensuring that exposure to a particular chemical does not interfere with the behavioral integrity of an animal. While the primary focus must always remain man, dependence upon a stable ecology demands that concern also be shown for the effects of pollutants on other organisms.

The list of the principal behaviors at risk also makes clear the enormous task facing those making decisions concerning permissible exposure levels. Priorities must additionally be set so that available resources can be optimally allocated.

Because the systematic study of behavioral and neurological effects is so new (e.g., Xintaras et al. 1974; Norton 1975; Weiss and Laties 1975), adequate information does not exist for any chemical. Therefore, almost any experimental work on the major coal technology pollutants will be welcome. Nevertheless, one can set priorities that seem sensible when attempting to stimulate new work in this area.

In all such work, emphasis should be placed on determining dose-effect or dose-response relationships. These will best lay firm groundwork for future judgments about pollutant levels that can be tolerated in the environment. This emphasis is important because we lack firm knowledge of the exposure levels to be encountered. It is also important to encourage studies that promise to deliver the most fundamental information about the actions of any agent since, in view of the state of development of the newer coal technologies, it is possible to specify neither the exposure levels nor the precise behaviors that someday may be of greatest interest. Comparative data on toxic substances and CNS-active drugs would be useful to aid in interpretation of results. Studies of interaction with other chemicals and chronic exposures are also important (e.g. ethanol, sedatives, tranquilizers). Indeed, the concerns expressed in section 6.1.1 regarding work with single chemicals versus mixtures and high versus low exposure levels are also relevant here.

Of the chemicals listed above as being of importance to coal-related technologies, carbon monoxide, various organic solvents such as toluene and carbon disulfide, irritants such as ammonia and aldehydes, and toxic trace elements such as mercury, cadmium, and lead appear to be of most importance with regard to nervous system effects.

Recommendations:

1. Sensory effects of CO need more study despite a long investigative history: e.g., it is still not known whether

exposures that produce 5 percent COHb levels affect vision (Laties and Merigan, 1979). It is also not completely clear how low CO levels affect the ability of humans to pay attention to boring tasks for prolonged time periods. The "vigilance" task has been a mainstay of research but there still remains much more to be learned about which parameters of performance maximize sensitivity to CO. Skilled performance, so intimately involved in automobile and truck driving and the operation of heavy machinery, should also be the focus of more work with CO in light of the possible increases in CO levels in the ambient air or as a result of coal combustion.

2. Techniques for the measurement of irritation potency should be further refined. In particular, the correlation between behavioral estimates of irritation and the older physiological reflex indices remains to be established and deserves systematic investigation (Alarie 1973; Wood 1979). Adaptation to irritants should be investigated because prolonged exposure to a substance may lead to pulmonary damage in persons who no longer notice the presence of the chemical.

3. More precise characterization of the behavioral changes produced by lead, mercury (both inorganic and organic forms), and cadmium appears essential. In particular, methods must be developed to characterize more accurately the types of behavioral change that now are covered by such terms as "mental confusion" and "mental disturbance," which often appear in epidemiological studies. Although sensory and motor system toxicity of heavy metals is a subject of increasing attention, few effects have been carefully studied. A firm scientific base is required for future work on the early detection, precise definition, and amelioration of deficits.

4. Damage to the central nervous system by trace metals sometimes does not become evident until it has progressed to irreversibility because of compensatory changes. The presence of this reserve capacity makes it essential to develop strategies for more sensitive measurement of damage.

6.4.2 Process-Specific Problems

6.4.2.1 Conventional Coal. For most of the substances released during conventional coal mining and use, little or nothing is known concerning their potential to cause neurotoxic effects. For some, such as carbon monoxide and mercury, at least a start has been made on characterizing CNS effects on both man and other animals (Evans et al. 1975; Laties and Merigan 1979).

Recent evidence that exposure to hydrocarbons such as methyl n-butyl ketone can cause behavioral effects raises concern regarding the potential neurotoxic effects that might arise from occupational exposure to the emissions from coal cleaning, coking, or combustion (Anger 1977). This concern is reinforced by the knowledge that carbon disulfide, also known to cause behavioral effects (Hanninen 1971; Levine 1976), is one of the possible constituents of the offgas. Other compounds that should receive special attention include the polycyclic aromatic hydrocarbons; the less complex hydrocarbons such as xylene, toluene, and phenols; carbon monoxide; and trace metals such as arsenic, lead, and mercury.

Recommendations:

1. Behavioral and neurological investigations along the lines suggested in section 6.4.1 should be supported. The chemicals that appear to deserve emphasis if conventional coal production increases are mentioned above.

6.4.2.2 Chemical Coal Cleaning. The solvents and microwaves used in these processes may have behavioral and neurotoxic effects.

Recommendations:

1. More research is needed to define how solvents can influence the performance of skilled behavior by both humans and animals, since it is in occupational settings that solvents such as TCE are most likely to be important in coal technologies. How solvents interfere with complex behavioral processes such as the ability to make subtle discriminations of stimuli should also be determined. Again, both human and

animal work would be desirable. Further research is also needed on sensory and motor deficits produced in both animals and man.

2. Research is desirable on how solvents modify electrophysiological variables such as event-related (evoked) potentials as well as other measures of nerve function.

3. The use of microwaves in chemical coal cleaning leads to the recommendation that work on possible behavioral and neurotoxic consequences of such exposure be encouraged. Due to safety considerations, animal work must be emphasized.

6.4.2.3 In Situ Gasification. The use of explosives to fracture underground coal seams could result in the creation of fissures not connected to the vent gas system. Should this occur, a number of trace gases, volatilized elements, and partially combusted hydrocarbons might be released to the surface. This could lead to both occupational and general population exposures. The trace gases and volatiles most likely to escape during coal combustion that have behavioral and neurological effects include: ammonia, carbon disulfide, trace organics, and volatile trace elements such as Li, Hg, Pb, and Cd (Jones et al. 1977).

As is the case with conventional coal combustion, the trace organics which might be emitted during in situ combustion are generally not well characterized. It is estimated that only 1,000 of the more than 10,000 organics believed to be present in trace amounts in coal tar have been positively identified (Braunstein et al. 1977). Trace elements such as Hg, Cd, and As also exist in a soluble form, and if present in sufficient concentrations, result in toxic effects.

Recommendations:

1. Because trace elements may exist in leachable forms, it is important that monitoring of water supplies be conducted to see that they do not become concentrated in the aquatic food chain.

See recommendations 3 and 4 in section 6.4.1.

6.4.2.4 Fluidized Bed Combustion. Carbon monoxide emissions are expected to exceed those from conventional coal-fired boilers because of the increase in temperature and decrease in excess air levels. This gas has been responsible for many occupational accidents and during adverse atmospheric conditions could pose a threat to nearby populations.

The solid wastes may be expected to contain trace metals: As, Be, Cd, Hg, Pb, Sb, Se, Te, Al, Fe, and Si. Exposure to these solid wastes can be expected to occur during disposal and through drinking water or food chain exposure should leaching occur.

Recommendations:

1. Further work on the behavioral effects of trace metals and carbon monoxide appears to be most relevant to this technology.

See recommendations 3 and 4 in section 6.4.1

6.4.2.5 Magnetohydrodynamics. Volatile trace metals can be expected to occur as part of the air emissions from MHD processes. These would include Hg, As, Zn, Ba, Cd, V, and Se (Matray 1976). On the other hand, the solid wastes resulting from MHD open processes can be expected to contain fewer heavy metals and trace organics due to the high temperatures of combustion than the wastes from standard coal combustion techniques (U.S. DOE 1978).

Occupational exposure to strong magnetic fields is likely to occur during MHD combustion of coal.

Recommendations:

1. If shielding cannot protect workers from the magnetic fields, much more should be learned about the health effects of exposure to such fields so as to allow for the setting of appropriate standards. The dose-effect relationship between exposure to magnetic fields and development of adverse neurological and behavioral effects should be studied. The fields encountered during occupational exposure with MHD combustion are much higher than those which have been demonstrated to have adverse effects upon biological systems (Kaufman and Michaelson 1974; Kleiner et al. 1975).

6.4.2.6 Coal-Oil Mixtures. No special problems should occur with the combustion of coal-oil mixtures that cannot be anticipated through consideration of the two constituents separately.

6.4.2.7 Cocombustion with Municipal Solid Waste. This process is expected to result in increased atmospheric releases of Pb, Br, and Cl at levels which could exceed acceptable ambient exposure levels (Narayanan 1979). Other volatilized elements may be released in increased quantities over those from coal alone, but are not expected to result in excessive exposures. These include: Sb, As, Cd, Hg, and F.

Recommendations:

1. Since lead may be the most important CNS poison associated with this technology, behavioral and neurological work with it should be encouraged. In particular, further research is needed to delineate more clearly the critical periods of exposure which induce various behavioral changes and whether

the changes are transient or irreversible. More behavioral work should be done on both etiologically important behaviors (e.g., ingestive, sexual, aggressive) and complex learned behavior (Rodier 1978; Damstra 1977; Cory-Slechta and Thompson 1979; Buelke-Sam and Kimmel 1979; Laties 1978).

See recommendations 3 and 4 in section 6.4.1.

6.5 Other Systemic Effects

6.5.1 Introduction

In this section, the potential for adverse health effects as a result of damage to target organs and systems other than the lung, gastrointestinal tract, skin, and the nervous system is discussed. Included in this section are cardiovascular, hematological, immunological, and neuro-endocrine effects.

An exhaustive treatment of this broad area is not possible as this would amount to a treatise on general pathology. Instead, attention will be drawn to those target organs and physiological systems most likely to be affected by physical and chemical agents involved in conventional and advanced coal technologies. This discussion will be limited to direct effects of the agent. Furthermore, carcinogenic, mutagenic, and teratogenic effects are specifically considered elsewhere.

Recommendations:

1. Methods should be developed for the quantification of the load of coal-related pollutants and the measurement of rates and routes of its metabolism by the liver. Interactions of metabolites of coal-related pollutants with chemical constituents of liver cells in relationship to hepatic injury also require further examination. It may be possible to use methods which detect injury-associated compounds in serum, exhaled breath, or urine to estimate extent of exposure and risk in man.

2. Research should be conducted in man on the importance of factors such as nutritional states, race, sex, and age which, acting in concert with exposure to coal-related pollutants, affect the cardiovascular system. In the design of animal experiments on exposure to environmental agents, factors known to be important in human cardiovascular disease should be included for study. Research on fundamental processes such as how energy is derived for cardiac work would provide a means by which the possible mechanisms of action of coal-related pollutants could be better understood.

3. Since the molecular mechanisms of hepatocellular injury by coal-related pollutants are poorly understood, better ways should be developed to define the chemical, functional, and structural events involved in hepatocellular injury by different agents and to characterize and quantify the different parameters of injury.

4. The early effects on the endocrine function of the kidney in renal disease induced by coal-related pollutants should be further characterized. In particular, efforts should be made to identify pollutants that cause specific inhibition of the synthesis, action, or degradation of hormones or vasoactive substances.

5. Support should be provided for studies of the relationships between the occurrence of renal damage and exposures to heavy metals emitted from coal technolcgies. Particular attention should be directed to the consequences of long-term exposures.

6. Animal models need to be developed to assist in understanding the binding capacity of the thyroid gland for handling iodine loads in various states of stress brought on by physical or chemical agents.

7. Studies of the effect on immune responsiveness of chronic low-dose exposure to environmental agents should be pursued in carefully selected areas. Physical and chemical agents which should be studied include drugs for which there is some indication of selective toxicity to the immune system.

8. Methods should be developed which would permit the rapid assessment of observed hypersensitivity reactions in order to determine whether an immunologic and mechanism is involved and whether more intensive studies of this mechanism should be pursued.

9. Characterization of absorption, retention, metabolic, and excretion rates for major identified coal-related pollutants via each plausible exposure route is needed.

10. Investigators responsible for toxicologic assessments of coal-related pollutants such as benzenes should employ in vitro bone-marrow methods that distinguish microenvironmental damage or stem-cell depletion as the cause of aplasia. Measurements of the colony-stimulating factor in the blood and urine should be performed.

11. A procedure should be developed to assess the effect of intermittent noise.

12. Discriminating ear protection devices are needed which are compatible with the mining industry.

13. The development, standardization, and validation in terms of human experience of methods for assessing the potential immunogenicity and allergenicity of industrial or commercial chemicals is urgently required in order to prevent or minimize environmental disease.

14. For identified coal-related pollutants, the environmental medium supplying the greatest portion of the total daily uptake to the general population should be identified.

15. Other physiological deficiencies which would inherently identify higher risk groups, e.g., enzymatic malfunctions and immature developmental state of the fetus and newborn infants, should be determined and quantified in terms of the general population affected.

6.5.2 Process-Specific Problems

6.5.2.1 Conventional Coal. Even though inhalation, dermal, and gastrointestinal penetration represent the major pathways by which materials associated with coal enter the body, the sites or organs ultimately affected may be distinctly removed from the site of exposure. For some substances, kidney or liver may be the primary target organ while other substances tend to accumulate in adipose or cardiac tissue or the brain. The toxicity of any particular substance will be a function of the dose of a chemical, the number of exposures, or the substance's metabolism, distribution, and excretion patterns, various organ concentrations, and its interaction with other chemicals.

Of special importance is the release of heavy metals into the environment as a result of coal combustion. Heavy metals tend to accumulate over long periods of exposure in specific tissues, for example, lead in the skeleton and cadmium in kidneys. Other heavy metals such as mercury are subject to biomethylation in the aquatic environment and to bioaccumulation of methylmercury in food chains. A wide variety of systemic effects may be caused by exposure to heavy metals in the human diet and in the atmosphere, including effects on the cardiovascular, immunological, neuro-endocrine, and other systems.

The physical agents such as noise, vibrations, and heat must also be considered. It is well documented that exposure to excessive noise results in hearing loss. Noise is perhaps the most ubiquitous of air pollutants, and significant noise levels may be associated with a number of coal industry processes. Mining is very noisy, as are the grinding and crushing operations used to prepare coal for combustion. OSHA and MSHA have set the allowable occupational noise exposure at 90 dBA for an 8-hour exposure. Noise levels can be higher for intermittent exposure and when protective gear which reduces the exposure to the permissible level is worn.

Underground miners have been found to have measurable hearing losses in comparison to the national average. Coal mining noise tends to be intermittent, which offers time intervals for functional hearing recovery. Even though hearing loss is known to be a consequence of coal mining and processing, very little research has been directed toward mitigation of otological effects.

Whole-body vibration has been implicated in the increase of various health effects such as musculoskeletal, circulatory, and digestive disorders. Workers in the coal industry may be occupationally exposed to whole-body vibration that could be associated with potential health effects of particular importance to job performance. Present knowledge is somewhat sketchy concerning vibration-related safety and health problems and the associated programs intended for their prevention or reduction with regard to coal industry workers. The potential adverse health effects of vibration exposure in the coal industry most effectively can be dealt with by first developing a better understanding of the extent and nature of the whole-body vibration problem. In addition to any short-term safety implications, there may be adverse chronic effects of occupational vibration exposure on the coal industry workers' health. Whole-body vibration contributes to adverse health effects in certain body systems such as circulatory, digestive, and musculoskeletal, but its exact significance cannot be defined.

High temperatures are found in some deeper mines, which make working conditions difficult. Occupationally required physical movement, under extreme heat, can lead to heat stress. As coal mines go to greater depths, the high temperatures and humidities characteristic of such depths make it difficult to maintain comfortable working environments. At these depths, heat and humidity increase as one moves progressively away from the shafts. Such exposure could produce muscle cramps, fainting, heat fatigue, heat stroke, and rashes. Exposure to extreme heat under conditions that require large amounts of physical movement can result in heat stress. When this occurs, the body loses its ability to control its temperature and death may result if proper first aid is not given.

The metabolic scheme and mode of action for most coal-related pollutants are unknown. Absorption, retention, metabolic, and excretion rates vary for each pollutant taken into the body and can also vary between individuals. Identification of these rates for specific coal-related agents would aid in the determination of dose-response relationships as well as total daily uptake values. Identification of mechanisms causing increased susceptibility within the population is necessary for identification of high risk groups.

Recommendations:

1. Information is needed on the adequacy of current heat stress practices and on the minimal conditions of heat and humidity that must be maintained to provide protection to deep mine workers.

2. Occupational safety and hygiene procedures should be developed to minimize heat stress in deep mine areas.

See recommendations 1 through 15 in section 6.5.1.

6.5.2.2 Chemical Coal Cleaning may lead to exposure to a variety of toxic metals and other elements--Hg, Cd, As, Se, Fl, Ni, Pb, Be--with the potential for a variety of systemic effects. Carbon monoxide may affect the oxygen-carrying capacity of blood with the possibility of effects on the central nervous system (see section on behavioral and neurotoxic effects). Metal carbonyls are volatile and pass into the bloodstream after inhalation, with various systemic effects possible. For example, nickel carbonyl has been reported to produce pathological lesions in the liver, kidney, adrenal glands and spleen of diseased workers, in addition to damage to brain and lung tissue.

Recommendations:

1. More information is needed on interaction between metals and other elements in both the animal models and human subjects, e.g., the protective role of selenium with respect to the toxic actions of mercury, cadmium, and arsenic has not yet been established in man.
2. Comparative studies should be made on metabolism of toxic metals in human subjects on high versus low dietary intakes of selenium.
3. The possible protective role of selenium in human cancer needs further study.

See recommendation 1 in Section 6.1.2.2.

6.5.2.3 In Situ Gasification has the potential for producing a wide variety of systemic effects. Carbon monoxide, carbon disulfide, and hydrogen cyanide are associated with hypoxia and other cardiovascular effects. Hematopoietic and immunologic effects may result from emission of volatile organic compounds.

Recommendations:

1. Mechanism of damage by organic chemicals to the hematopoietic system are poorly understood. Further studies should identify those factors that govern individual susceptiblity to hematopoietic effects.

See recommendations 7 and 8 in section 6.5.1.

6.5.2.4 Fluidized Bed Combustion may produce systemic effects via release of carbon monoxide, by trace metals, and heat stress.

Recommendations:

1. Further information is needed on human response to multiple stress factors including metal metabolism in individuals undergoing heat stress. The role of perspiration as a route of excretion of metals requires further study.

See recommendation 1 in section 6.5.2.1.

6.5.2.5 Magnetohydrodynamics seem not to produce major systemic effects except for the possibility of increasing toxic metals in drinking water and aquatic food chains.

6.5.2.6 Combustion with Municipal Solid Waste may lead to release of volatile elements such as cadmium. The latter accumulates in kidney tissue over most of the human life span. It has been estimated that continued release of Cd into the environment at current rates plus future industrial expansion, might lead to toxic kidney levels in senior age groups by the year 2000.

Recommendations:

1. Investigations into the toxicity and metabolism of cadmium in animal models and man should be continued.

2. Individuals occupationally exposed to cadmium should be studied prospectively to test whether lung cancer is associated with respiratory intake of cadmium.

3. Further investigations should include:

   - the ability of cadmium to induce specific metal binding proteins such as the metallothioneins;
   - the role of metallothioneins in the metabolism of essential trace metals in man such as copper and zinc;
   - the development of sensitive analytical methods to measure metallothioneins in tissues; and
   - the application of these tests to use metallothioneins as an early indicator of renal damage in man.

6.5.2.7 Coal-Oil Mixtures. There should not be a special risk of systemic effects from this process.

6.6 Carcinogenic, Mutagenic and Reproductive Dysfunction Effects

6.6.1 Introduction

This section deals with the possible harmful effects of coal technologies through the production of malignancies, germ cell mutation, or interference with germ cell processes.

It is believed that exposure to the fugitive emissions from coal combustion and conversion processes may have a significant potential for carcinogenic, mutagenic, and reproductive dysfunction effects. These fugitive emissions may contain such potentially hazardous substances as trace metals, radionuclides, and polycyclic aromatic hydrocarbons which are found at highest concentrations in the finest particle-size ranges of the effluent flyash (Aranyi et al. 1979).

This relative enrichment occurs through a process of condensation and is due to the greater surface to mass ratio of the smaller particles. The fine particulates are most difficult to remove from the combustion stream, and since they are in the respirable size range, they also represent the greatest inhalation hazard. Their potential to impact on the cellular level is a major concern (Aranyi et al. 1979).

Estimates of particulate emissions from coal combustion and conversion vary. Based on 1973 estimates of the Environmental Protection Agency, close to 6 million tons of flyash are being dispersed annually into the atmosphere from the combustion of coal in United States. Particulate emissions from coal combustion and conversion by the year 2000 are estimated to reach one million tons annually (Van Hook 1977). These emissions will be predominantly in the respirable range and will contribute both trace elements and radionuclides.

It is well recognized that coal contains many minor and trace elements. The processing of 20,000 tons/day of coal that contains 1 ppm of a trace element can result in 40 lbs/day of this element in the plant streams (Young 1979).

Trace element pathways within the conversion processes may include adsorption on particulate matter, inclusion in condensate, deposition on equipment surfaces, inclusion in byproducts and final products, and emission as fugitive pollutants (Young 1979). While the majority of elements are expected to remain in the solid by-products such as ash and char, other byproducts such as tars may also contain small amounts (Young 1979).

Arsenic, beryllium, mercury, selenium, cadmium, and lead are expected to volatize during coal combustion, resulting in possible fugitive emissions. It is acknowledged to be extremely difficult to assess the direct human health effects of coal combustion-derived hazardous elements. It can be anticipated that their accelerated release from increased coal use will add, perhaps significantly, to the ambient atmospheric loading from all other sources (Van Hook 1977). It should also be noted that the possibility exists for synergistic actions with coal-derived and other organics and organic chemicals in the atmosphere, and these actions may become more important in determining organism response to increased ambient levels.

The three effects considered will be examined in respect to suspected agents or processes. Immediately following this introduction, the suspect processes and associated agents present (or possibly present) in the various technologies are listed in Table XIV along with indications of the agent or process is known or suspected of having carcinogenic effects, mutagenic effects on the germ cell, or injury to the reproductive function.

This chapter is divided into three sections listed above: carcinogenesis, germ cell mutations, and reproductive dysfunction. In each section, the issues considered are the means for detection and evaluation of the suspect processes or agents for the effects in question, the means for chemical identification and quantification, and available test methods.

6.6.2 Carcinogenesis

Carcinogens have been identified in many phases of coal extraction, upgrading, and end use. Exposure to these agents is certainly among the greatest hazards from expansion of coal technologies. For this reason, they may become the controlling factor(s) in determining the feasibility and the degree of control required to achieve rapid development of many of the coal technologies. High priority should therefore be assigned to this consideration.

Concern for the carcinogenic effect of coal dates back several hundred years, when scrotal tumors were observed in chimney sweeps as a result of exposure to soot. The initiation of research for the active carcinogenic substances in soot led to the identification of benzo(a)pyrene as a carcinogen in experimental animals, thus implicating polynuclear aromatic hydrocarbons (PAHs) as potential carcinogens in man. Coal combustion results not only in the formation of PAHs but also of organics, trace metals, radionuclides, sulfur and nitrogen oxides, and unidentified substances.

The 1980 Energy Security Act proposes a significant increase in the use of coal in the U.S., not only by conventional coal combustion but also by a number of advanced coal technologies which may possibly increase the number of potential carcinogenic agents in our environment. Table XIV shows a list of the suspect processes and associated agents that are present or possibly present in the various coal technologies which can be considered "hot spots" for potential health hazards.

Carcinogenesis studies involving complex mixtures of carcinogens are more complicated, for obvious reasons, than those dealing with only a single carcinogen. It is well known from animal studies that additive, synergistic, and inhibitory effects can occur when animals are exposed to several carcinogens simultaneously. In addition, since carcinogenesis in experimental animals, as well as in humans, is thought to be a multistage process, the possibility exists that besides carcinogens, a number of tumor initiators, cocarcinogens, and promoters may be associated with the various coal technologies. For example, diesel fumes, coal dust, and cigarette smoke are all believed to influence the induction of bronchiogenic carcinoma in miners. While exposure to any single agent may not cause a high potential for carcinogenic response, exposure to several agents simultaneously may lead to an increased risk of cancer. It has been shown that SO_x can enhance the number of lung squamous cell carcinomas when rats are exposed to benzo(a)pyrene plus SO_2 over the number when rats are exposed to benzo(a)pyrene alone (Laskin et al. 1976). Similarly particulates seem to promote the carcinogenic action of PAHs through adsorption to particle surfaces which may effectively increase localized exposure. Other compounds such as certain phenols, PAHs, alkanes, and iron oxides, which are present in

TABLE XIV

AGENTS AND PROCESSES OF INTEREST FOR POTENTIAL CARCINOGENIC, MUTAGENIC, OR REPRODUCTIVE EFFECTS

Technology/Pollutant	Carcinogenic Effects	Carcinogenic Cofactor	Mutagenic Effects	Reproduction Effects
Coal Extraction				
Diesel Engine Emissions	X	X	X	X
Coal Transport				
Fugitive Dust	X	X	X	X
Surfactants	X	X	X	X
Physical Coal Cleaning				
Coal Dust		X		
Coal Float-Perchloroethylene, gasoline	X	X	X	X
Coal Pile fires-combustion emissions	X	X	X	X
Chemical Coal Cleaning				
CO				X
Metal Carbonyls	X		X	X
H_2S				X
Fine Dust		X		
Metals				
As	X	X	X	X
Cr	X	X	X	X
Se	X	X	X	X
Ni	X		X	
Be	X		X	
Cd	X			X
Pb	X			X
In Situ Coal Combustion				
CO				X
H_2S				X
COS				X
CS_2				X

TABLE XIV (Concluded)

AGENTS AND PROCESSES OF INTEREST FOR POTENTIAL CARCINOGENIC, MUTAGENIC, OR REPRODUCTIVE EFFECTS

Technology/Pollutant	Carcinogenic Effects	Carcinogenic Cofactor	Mutagenic Effects	Reproduction Effects
In Situ Coal Combustion (Continued)				
SO_2		X		
Thiophenes			X	
Volatile organics (PAHs + lmw HCs)	X	X	X	X
Volatile trace elements	X	X	X	X
Pyridines, quinolines, indoles, phenols, soluble metals (emitted to H_2O)	X	X	X	X
Fluidized Bed Combustion				
CO				X
PAHs	X	X	X	X
Limestone dust-respirable particulates		X		
Trace metals in solid waste	X	X	X	X
Magnetohydrodynamic Combustion				
Magnetic fields				
Particulates	X	X	X	X
Alkali salts		X		
High voltages				
Municipal Solid Waste-Coal Cofiring				
Trace elements	X	X	X	X
Particulates		X		
Chlorinated HC from burning plastics	X	X	X	X
Coal Oil Mixtures				
Additives	X	X	X	X
Dust		X		

coal combustion emissions and effluents, are known carcinogens, cocarcinogens and/or promoters. For example, pyrene and benzo(e) pyrene have been shown to be cocarcinogenic when applied simultaneously with benzo(a)pyrene to the skin of mice (Van Duuren et al. 1978). Certain phenols have been shown to have both cocarcinogenic and promoting activities (Van Duuren et al. 1978). These promoters and cocarcinogens are present as a result of technology; others may be introduced through personal habits such as the use of therapeutic drugs, in diets, or as emissions from other industrial processes. Thus, the importance of cofactor relationships occurring as a consequence of simultaneous exposures to combustion emissions, pollutants, and other common chemical and physical agents cannot be overemphasized.

Test systems presently relevant to determining the carcinogenic potential of agents associated with coal technologies fall into the following four categories:

- bacterial mutagenesis assays,
- mammalian mutagenesis assays,
- _in vitro_ oncogenesis transformation assays,
- _in vivo_ carcinogenesis systems which include inhalation, skin carcinogenesis, lung adenoma, lifetime feeding, and subcutaneous injection assays.

In some instances a correlation can be made between the carcinogenic and mutagenic activities of chemical carcinogens. The bacterial mutagenesis assays, e.g.,the Ames assay, are useful tests because they are relatively inexpensive, short-term, and permit detection of a wide variety of mutagens that can be subsequently tested for carcinogenicity. As a first screen to be followed by other tests, the Ames test has shown good results except with certain classes of carcinogens such as metals where the Ames test is of limited value.

The mammalian mutagenesis assays offer promise as prescreens since they seem to provide both a qualitative as well as a quantitative correlation, but they are more expensive to perform and require more time than the bacterial tests. Both the bacterial and mammalian mutagenesis assay should be performed with and without a metabolic activation system in order to detect both procarcinogens and carcinogens.

Although more expensive and time consuming than the mutagenesis assays, the *in vitro* transformation systems also show potential as prescreens for carcinogens. Their major disadvantage concerns the reliability of early indicators of oncogenic transformation. If the *in vitro* transformation assay must be carried out to the point of injecting potentially transformed cells into an animal to demonstrate tumor-causing activity, then the expense and time involved are the same as, or possibly longer than, that required in some in vivo carcinogenesis tests.

The various *in vivo* carcinogenesis tests are obviously the most direct ways to determine the carcinogenic potential of an agent; however, they are extremely expensive and time consuming to perform.

Another major problem concerns the tissue and species specificities of many carcinogens. For example, what is positive for skin is not necessarily positive in the lung and vice versa. It is generally recommended that a battery of tests, as discussed above, be employed to determine the carcinogenic potential of an agent. This permits identification of chemicals causing similar end points but operating by different mechanisms.

Interpretation of data from these carcinogenesis test systems is still very difficult, and risk assessment for humans is not presently practical. Nevertheless, if an agent associated with the various coal technologies gives positive results in one or more of the carcinogenesis assays, appropriate control measures should be undertaken in order to protect individuals from possible exposure.

All of the above carcinogenesis test systems can provide valuable information concerning the carcinogenic potential of complex mixtures associated with the various technologies, though it must often be qualitative rather than quantitative. Then, through the use of various analytical procedures, an estimation can be made of the quantities of this agent associated with a particular process. This provides valuable information on the relative risk posed by a given agent. Nevertheless, the determination of the carcinogenic potential of complex mixtures should be performed as a first line of defense followed by fractionation, identification, and quantitation of specific agents.

Recommendations:

1. Determine the carcinogenic, cocarcinogenic and promoting activities of complex mixtures associated with the various coal related technologies. Because of exposure to the lungs and skin, these systems should be the primary carcinogenesis systems used.

2. Investigations are needed of possible direct additive and synergistic effects of carcinogens known to be present in the coal related materials.

3. The role of various PAHs from coal-related materials as cocarcinogens and/or tumor promoters in the lung and skin should be investigated. The lung adenoma and skin two-stage system should be the systems of choice based on the extensive data available in these systems.

4. If complex mixtures are found to have carcinogenic, cocarcinogenic and/or promoting activities, a fractionation of the mixtures should be undertaken in conjunction with testing each fraction for activity.

5. The role of sulfur oxides and nitrogen oxides as potential cofactors in carcinogenesis should be investigated.

6. Investigations of possible direct and synergistic effects between coal-derived metals and other inorganic and organic substances as related to carcinogenesis should be performed.

7. Fine particulates should be investigated as vehicles for transport of carcinogens to target lung tissues.

8. A search should be conducted for carcinogenicity indicators other than benzo(a)pyrene.

9. Definitive investigation of diesel exhaust is needed related to its potential to cause carcinogenic effects.

See recommendation 3 in Section 6.1.1.

6.6.3 Mutagenesis

Concern for germ cell mutations is increasing with awareness that a number of chemicals are potentially injurious to the germ cell.

The public health issue addresses the possibility that population exposure may lead to heritable mutations which could affect later generations. A number of the short-term tests used for the evaluation of potential carcinogens also involve assessment of the possibility of DNA damage or the occurrence of mutations in somatic cells.

It is true that there are currently no available techniques of adequate sensitivity or efficiency to detect the occurrence of injurious mutations in human populations resulting from exposure to chemicals. Nevertheless, the entire body of biological information available at this time clearly points to the fact that such mutations can occur from mutagenic chemicals which reach the gonads and that they can produce deleterious effects in the offspring of the test animals. The absence of techniques adequate at this time to detect such effects in humans is no reason for delaying the application of a prudent pretesting approach to determination of whether such injury is likely to occur in the progeny of the exposed population.

Many organic chemical carcinogens are mutagenic in a variety of test systems; if they reach the germ cells through normal routes of exposure, they can be presumed to produce heritable mutations. However, as noted below, pharmacokinetic processes governing their transport, activation, or deactivation will play a dominant role in determining whether effective doses reach the gonads. Thus, the polynuclear aromatic hydrocarbons are mutagenic and carcinogenic but because of the local tissue processes leading first to activation and then to inactivation, their local carcinogenic risk may be greater than their hazard to the germ cell.

There are a large number of possible mutagens present at the various stages of the coal technologies considered by this panel. Table XIV identifies some of these. Priorities will have to be established on the basis of the probable extent of exposure, existing knowledge, and use of the short-term screening tests identified below. In general, chemicals reactive with DNA directly or through metabolic activation should be regarded with suspicion.

There is available a substantial information source on mutagens (generally pure or defined chemical compounds) in the Environmental Mutagen Information Center (EMIC) at Oak Ridge. Where there is no existing information and there is basis for suspicion (Table XIV) and likelihood of exposure, screening will be indicated. The bacterial revertant tests (Ames) are simple and reasonably reliable for initial screening.

In some instances, mutagenic agents in Table XIV are identifiable as particular chemical entities. In such cases, quantification could follow usual chemical analytical procedures. In most instances, however, the mutagenic agents will not be directly identifiable as chemical entities and, in fact, it may not be practical to make such an identification. Bacterial revertant assays such as the Ames test are readily applicable for the testing of mixtures of agents and, indeed, can also give quantitative results. They should be applied without microsomal activation as well as with graded additions of microsomal components, since in some cases an excess of the enzyme will yield a reduction in the number of mutations produced. However, quantitative interpretation of such tests is often confused by the complex interactions between chemicals. Additionally, the net potency of such mixtures may be very different from the sum of the individual components because of interaction of comutagenic and antimutagenic activity. Nevertheless, such assays have a very useful purpose in screening agents where the chemical composition is unknown; mixtures separated and tested for mutagenicity can and should be examined chemically as well.

Tests relevant to germ cell mutations fall into three categories:

- direct or indirect DNA injury or stimulation of repair-mutagenicity assays using bacterial or other microorganisms
- chromosomal mutations based on cytogentic tests in mammals
- whole animal tests for gene or point mutations, for example, those using Drosophila or the specific locus test in mice, the dominant lethal test in mammals, and the heritable translocation test in rodents.

The first group is also applicable as an indication of potential carcinogenicity and is mentioned in the section on carcinogenicity. The latter two groups of tests are specifically related to germ cell mutations. In the latter group, the specific locus test in mice is lengthy, extremely expensive, and is probably not practicable except in very special cases. The *Drosophila* test is more realistic, less cumbersome, and less expensive. The dominant lethal test in mammals is regarded as less sensitive than some of the other tests, but is a practical laboratory procedure. It is generally recommended that a battery of tests including at least one procedure from each group be employed.

An important distinction needs to be made between the use of tests with isolated systems and those in whole animals. In whole animals, the test agents are subjected to the entire array of biological factors of transport and metabolic alteration which together determine access of the agent or (its activated form) to the gonads. Note, however, that both transport and metabolism in the *Drosophila* may differ from that in mammals. In the isolated systems tests, these factors do not prevail in the same degree. In any test involving the use of isolated systems, an estimate of risk to the complete organism requires a pharmacokinetic study to determine the extent of access of the active agent to the gonads.

The details of the procedures identified above will not be described here; for relevant references, see DHEW 1977 and the WHO Criteria Document No. 6 (WHO 1978).

Recommendations:

1. Investigation of possible direct and synergistic effects between coal-derived metals and other inorganic and organic substances as related to heritable mutations should be performed.

2. The mutagenic potential of diesel exhaust should be investigated.
3. The kinds of tests available for determining mutagenic end points should be evaluated as should the approach (tier vs. battery).
4. Research should be undertaken to improve the application of short-term tests to the identification of active (including enhancing or inhibitory) components of complex mixtures of mutagenic or transforming agents.

6.6.4 Reproductive Dysfunction

It is generally acknowledged that until comparatively recently, little attention has been focused on occupational and ambient exposure-related, reproductive hazards compared to those potentially related to carcinogenic and/or mutagenic effects.

Although exposures to environmental agents can occur in one of three principal ways, it is recognized that some overlap for specific chemicals can occur. Occupational exposure usually involves a rather well-defined group of workers and occasionally includes their families and associates as a result of home contamination. Ambient exposure occurs via media such as air, water, and food variously contaminated by environmental chemicals. It should be noted that specific populations of exposed and unexposed individuals are often not available for study and hence the clear establishment of etiologic relationships is limited to severe disease, e.g., lead encephalopathy, Minamata disease. The third category of exposure is accidental exposure which can occur through a specific contamination incident e.g., the dioxin incident in Seveso, Italy, or the PBB incident in Michigan. To date, however, unambiguous evidence is lacking concerning human reproductive dysfunction resulting from these two episodes.

It is well recognized that many chemical agents to which an individual may be exposed may be overtly or potentially harmful causing structural or functional change immediately, after a considerable lapse of time, or after some indeterminate time following exposure. There are many who believe that it is within this last category, subacute effects, that most impact on reproduction occurs (Wilson 1977a).

Of principal concern is significant alteration in the physiological process of reproduction including adverse effects such as heritable changes in genetic material, adverse effects on sperm, infertility, pregnancy loss, prenatal and postnatal retardation, physiological and behavioral diseases in offspring, structural malformations, malignancy induced during gestation, and other transplacental effects. It is apparent that the significance of effects at each stage of reproduction needs to be evaluated separately (NIOSH and SOEH 1979).

It should be recognized and emphasized that although the incidence of birth defects, spontaneous abortions and stillbirths among the human population are quite high, with as many as seven percent of all newborns being born with birth defects in the U.S. annually, the causes of the vast majority of these defects are not known (Wilson 1977a; Stellman 1979).

Table XV lists the presently known causes of developmental defects in man (Wilson 1977a). Only about 20 percent can be assigned primarily to genetic transmission and an additional 5 percent may be related to gross or quantitative abnormalities in the chromosomes. It should also be noted that all currently known environmental factors together do not account for more than an additional 10 percent of developmental defects in man. Hence, as many as 70 percent of all defects are of unknown origin and, while hundreds of agents may be capable of causing reproductive failure or of inducing germinal and/or somatic mutation, the actual magnitude of their effect on human reproductive health has not been quantified (Stillman 1979). It should be noted that most of the presently unaccounted for causation may indeed stem from combinations and interactions among two or more of the factors listed, or with as yet unidentified environmental and/or hereditary causes (Wilson 1977a). Although not demonstrated in man to date, animal studies have suggested that multiple environmental factors at low dosages may interreact to cause additive or potentiative effects on development (Fraser 1977).

That toxic agents can manifest themselves in a variety of ways has been well documented. These can include the following: adverse effects on the male or female reproductive cycle, possibly leading to infertility; production of insufficient or defective sperm; prevention of the successful implantation of fertilized ova; or inducing of

TABLE XV

PRESENTLY KNOWN CAUSES OF DEVELOPMENTAL DEFECTS IN MAN

Solely or mainly by genetic transmission		20%
Chromosomal aberration		3-5
Environmental causes		
Ionizing radiations		<1
Infections		2-3
rubella virus	varicella virus	
cytomegalo virus	toxoplasma	
herpes simplex virus	syphilis	
Maternal metabolic imbalances		1-2
endemic cretinism	phenylketonuria	
diabetes	virilizing tumors	
Drugs and environmental chemicals		4-6
(see subsequent tables)		
Combinations and interactions		?
Unknown		65-70

Source: Wilson 1977a.

functional defects not readily observed at birth and hence not associated with reproductive failure (Stellman 1979).

Figure 12 illustrates a schematic presentation of some of the modes of reproductive dysfunction and also shows which parent may be at risk (Stellman 1979). Several modes of action by environmental agents leading to male reproduction failure are possible. There may be direct damage of male germ cells leading to mutation and/or infertility; anatomical lesions may be present in spermatogenic tissue; and loss of libido and impotence may occur.

To date, the majority of evidence on the effects of toxic agents and paternal exposure would suggest that the most likely outcome is infertility in males or spontaneous abortion in their sexual partners (Stellman 1979). It has been thought to be far less likely for birth defects, stillbirths, or childhood diseases to result from paternal exposure. It should be noted that there is some evidence that toxic agents may penetrate the blood-testis barrier and enter the testicular fluid and that such penetration can be the cause of false-negative results in dominant-lethal testing of environmental mutagens (Stellman 1979).

Some evidence is available that suggests exposure of the mother to foreign chemicals may interfere with normal reproductive organ system function. Another aspect of maternal organ dysfunction may arise from the presence of foreign substances absorbed from the mother's bloodstream into the uterine fluid. Trace metals, as well

TYPE OF EFFECT	PARENT AFFECTED	
ORGAN DYSFUNCTION		
insufficient/defective sperm	♂	
an ovulation/defective ova		
implantation defects	♂	♀
spontaneous abortion	♂	♀
GENETIC DEFECTS	♂	♀
GESTATIONAL TOXICANTS		
pre-embryonic	♂ (semen)	♀
embryonic		♀
fetal		♀
POST-PARTUM TOXICANTS		
via lactation		♀
via inhalation	♂	♀

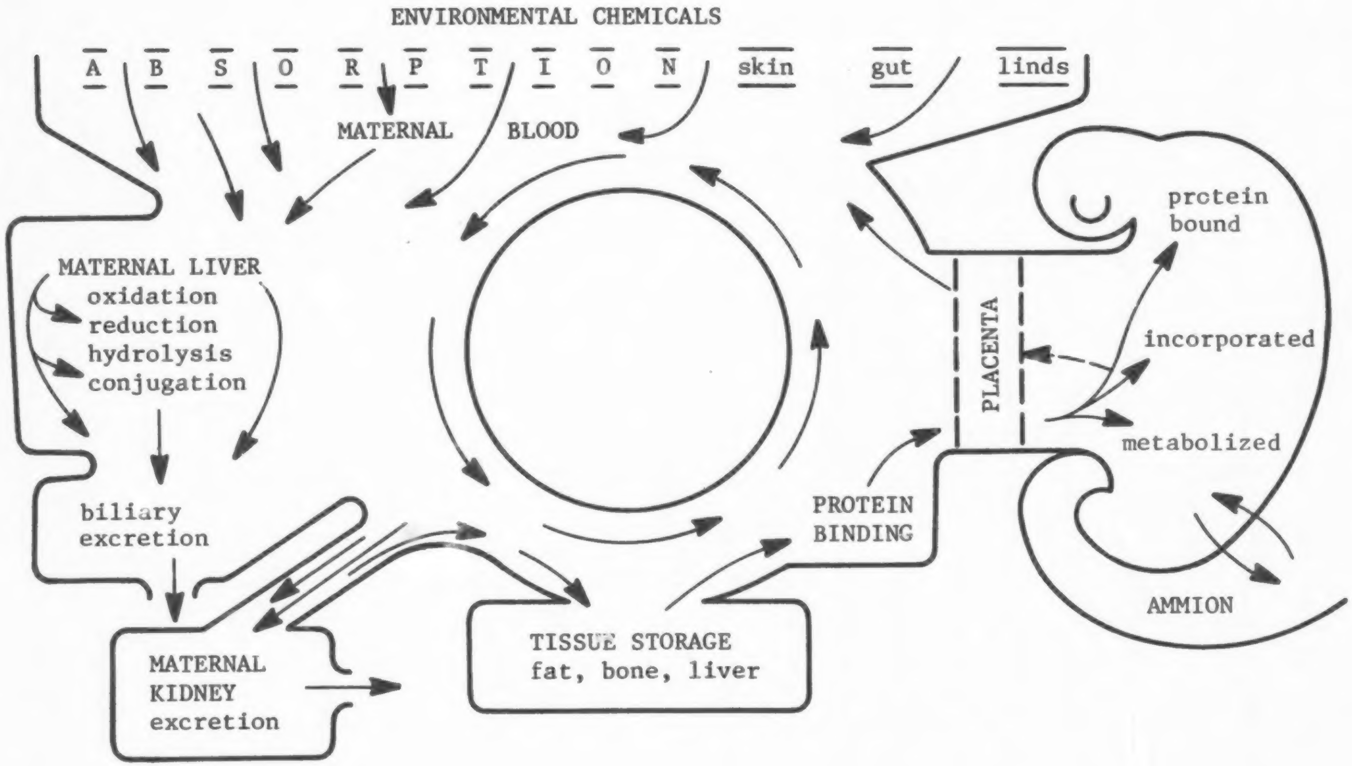
Source: Adapted from Stellman 1979.

FIGURE 12
SOME POTENTIAL MODES OF
REPRODUCTIVE DYSFUNCTION

as a variety of drugs, have been shown to be present in uterine secretions (Wilson 1977a; Stellman 1979).

It is now widely accepted that although the mammalian conceptus is enclosed within the uterus and semiseparated from maternal blood by the placenta, it may nevertheless be exposed to some fraction of the concentration of most chemicals in the maternal bloodstream (Wilson 1977a). Figure 13 illustrates the homeostatic devices that tend to protect the mammalian embryo from chemicals absorbed into the maternal bloodstream (Wilson 1977a). While the factors that govern the peak concentration and half-life of chemical agents in the embryo remain poorly understood, most agents are assumed to reach the embryo but not necessarily in biologically effective doses (Wilson 1977a). Although some chemical agents can get into the embryo in pharmacologically active amounts but leave no permanent alterations, it should be stressed that others produce dose-related alterations that can be correlated with later structural defects (Ritter 1971).

The placenta does not selectively protect the intrauterine organism from harmful agents administered during pregnancy and, indeed, has been referred to as a sieve (Wilson 1977a; Harbison 1978). Except for compounds with high molecular weights and those with strong electronegative or electropositive charges, almost all pharmacologic substances can and do pass from the maternal to fetal bloodstream. Generally, substances with a molecular weight of less than 600 pass the placental barrier (Harbison 1978), although it


ENVIRONMENTAL CHEMICALS
A B S O R P T I O N
skin
gut
linds
MATERNAL BLOOD
MATERNAL LIVER
oxidation
reduction
hydrolysis
conjugation
biliary excretion
MATERNAL KIDNEY excretion
TISSUE STORAGE
fat, bone, liver
PROTEIN BINDING
PLACENTA
protein bound
incorporated
metabolized
AMMION

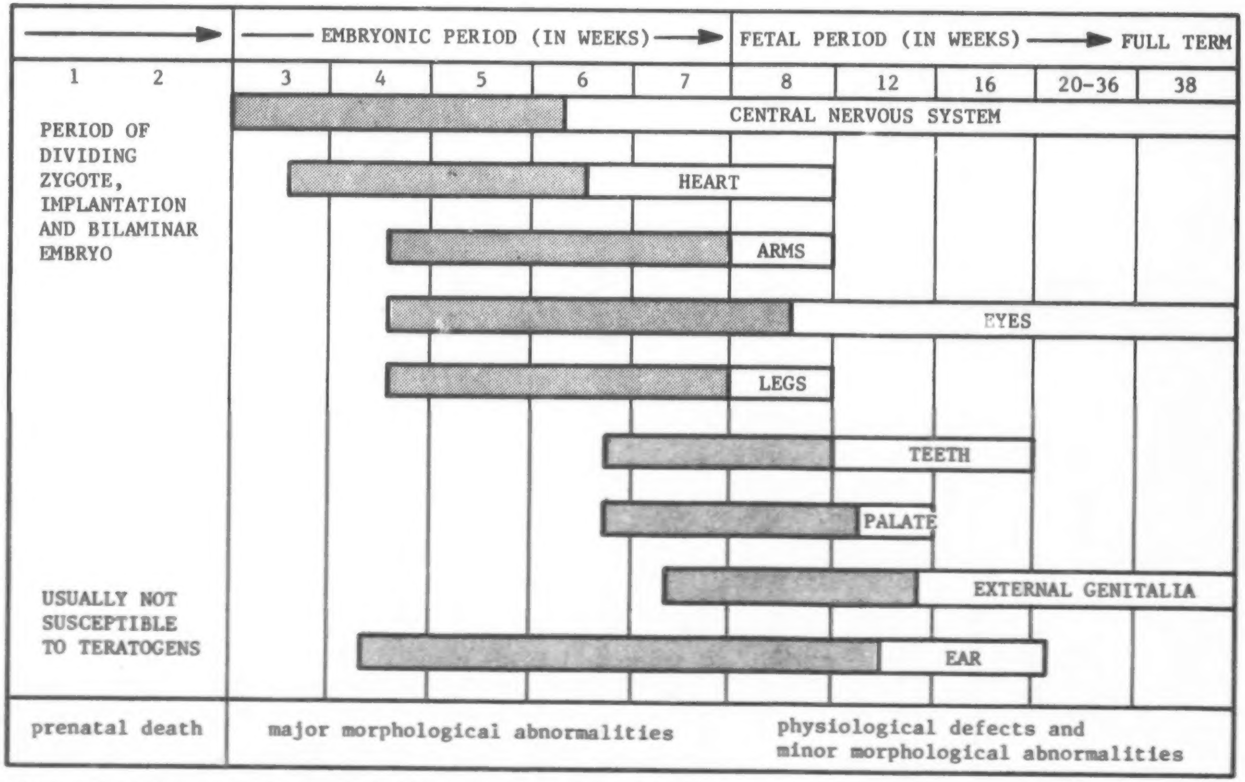
Source: Wilson, 1977

FIGURE 13
DIAGRAM OF THE HOMEOSTATIC DEVICES THAT TEND TO PROTECT THE MAMMALIAN EMBRYO FROM CHEMICALS ABSORBED INTO THE MATERNAL BLOOD STREAM *

should be noted that polarity is a factor and compounds of greater molecular weight can pass the placental barrier.

A teratogenic response is determined by both the time of exposure as well as the chemical reactivity of the material (Wilson 1977a; NIOSH and SOEH 1979; Stillman 1979; Fraser 1977; Ritter et al. 1971; Harbison 1978). Figure 14 illustrates a schematic representation of human development and the sensitive periods for maldevelopment. The shaded areas represent highly sensitive periods while the clear areas represent stages that are less sensitive to teratogens (Harbison 1978). Differences of placental transfer have been observed between species. Table XVI lists the comparative gestational development of man, rat, mouse, rabbit, and hamster (Harbison 1978). Placental transfer can hence be expected to vary during gestation and between species making generalizations and anthropomorphizing animal data difficult (Harbison 1978).

Although a teratogenic agent has been classically defined as one that induces structural malformations during the gestational stage of development, recently this definition has been expanded to include aberrations of structure, growth, and function, whether caused by genetically determined factors, by environmental factors, or by an interaction of genetic and environmental factors. Hence, the complete spectrum of adverse reproductive outcomes which might be related to exposure to toxic agents can range from decreased fertility through fetal loss, growth retardation and congenital



Note: Shaded areas represent highly sensitive periods; clear areas represent stages that are less sensitive to teratogens.

SOURCE: HARBISON, 1978.

FIGURE 14
SCHEMATIC REPRESENTATION OF HUMAN DEVELOPMENT AND SENSITIVE PERIODS FOR PRODUCTION OF MALDEVELOPMENT.

TABLE XVI

COMPARATIVE GESTATIONAL DEVELOPMENT

	Man	Rat	Mouse	Rabbit	Hamster
Implantation period	6 1/2 days	8 days	5 days	9 days	7 days
13 to 20 somites	27 days	11 days	9 days	10 days	9 days
End of embryonic period	12-14 wk.	14 days	13 days	11 days	10 days
End of metamorphosis	20 wk.	17 days	17 days	15 days	14 days
Fetal development	20-34 wk.	18-22 days	18-20 days	16-32 days	15-16 days
Parturition	36-40 wk.	21 days	19 days	32 days	15 days

Source: Harbison 1978.

malformations, to childhood or even adult morbidity (Wilson 1977a; NIOSH and SOEH 1979; Stellman 1979; Fraser 1977; Ritter et al. 1971; Harbison 1978; Barr et al. 1979).

Examples of environmentally induced mutations, another class of dysfunction which results in transmissible defects, are less readily available. Hence, while it is reasonably clear that a large number of environmental agents can induce changes in the genetic structure of somatic and germinal cells, the impact of this on birth defects and other adverse reproductive outcomes has not yet been quantified (Stellman 1979). However, it has been suggested that an increased mutation rate will have an immediate and substantial impact on the frequency of dominant mutational effects and hence result in an increased morbidity rate (Stellman 1979). Although it has been stated that mutation is a firmly established mechanism of teratogenesis known to arise from both chemical mutagens and ionizing radiation, it is nevertheless extremely difficult to extrapolate its actual impact on reproduction.

An additional broad category of toxic reproductive agents that can be encountered is post partum toxicants, environmental agents to which a neonate may be exposed and suffer adverse effects. Such exposure can be directly related to parental occupational or ambient exposure or breast milk. The magnitude of such potential exposure on the health of neonates and others thus indirectly exposed is not known.

The largest class of effects that can potentially result from exposure to toxic agents in utero are those which adversely affect normal functioning. These may also constitute the most numerous problems associated with such exposure since they comprise biochemical, behavioral, as well as other defects, many of which are largely uncataloged (Barr et al. 1979).

Table XVII lists metals tested for embryotoxicity in animals (Wilson 1977a). As depicted in this table, metals and related elements appear as a group to have considerable embryotoxic potential. Of 25 tests with various metal-containing compounds in several species, 17 of the tests revealed unequivocal teratogenicity while 20 showed increased rates of intrauterine death. It should be noted that in addition to mercury, a proven human teratogen, two other metals have, to some degree, been implicated as embryotoxic in man; these are lead and lithium (Wilson 1977a; Wilson 1977b). While the general reactivity of ions of heavy metals with biological chemicals, particularly with enzymes, is well established, exact sites of action of these substances in the embryo are, for the most part, not known. Little is known concerning the manner in which heavy metals cross the placenta or about their effects on the transfer of nutrients. The Minamata disaster, in which mercury was ingested by pregnant women, vividly demonstrated that methyl mercury is capable of adversely affecting the developing human fetus (Murakami 1971).

TABLE XVII

METALS TESTED FOR EMBRYOTOXICITY IN ANIMALS

		Species Showing Specific Defects			
Compound	Species Tested	MAL	IDR	IGR	None
Al (chloride)	1	1			
As (arsenate)	3	3	3	2	
Cd (various)	3	3	3	2	
Cr (trioxide)	1	1?	1	1	
Cu (sulfate)	1	1?	1		
Ga (sulfate)	1	1?	1		
Hg (methyl)	4	4	4	3	
In (nitrate)	1	1	1		
Li (carbonate)	4	2	2		2
Ni (acetate)	1	1?	1		
Pb (various)	3	2	3	2	
Te (H_2TeO_3)	1	1			
Tl (sulfate)	1	1?		1	

Source: Wilson 1977a.

MAL = Malformations; IDR = Death or Resorption; IGR = Growth Retarded.

There is strong likelihood that the fetus is exposed to considerable amounts of carcinogenic and cytotoxic material after maternal exposure to the polycyclic aromatic hydrocarbons. While these toxicants may be of maternal, placental, or fetal origin, there appears to be little doubt that the products of reactions involving polycyclic aromatic hydrocarbons and aryl hydrocarbon hydroxylase are responsible for adverse fetal effects (Juchalo 1973; Kelman 1979). These compounds are unusual because prior exposure may lead to the release of materials more toxic to the fetus than the original compound.

Additional compounds (or classes of compounds) with reproductive dysfunction potential that can result from coal technologies described in this report include: methane, carbon monoxide, hydrogen sulfide, carbonyl sulfide, carbon disulfide (Morris et al. 1979), NO_x, metal carbonyls, sulfur dioxide, thiophenes and volatile organics (PNAs, low molecular weight hydrocarbons) from in situ coal gasification air emissions and pyridines, quinolines, indoles, phenols, and soluble metals from water emissions. The sulfur contained in coal will appear primarily as H_2S and to a lesser degree COS and CS_2 in coal combustion processes. Chronic exposure to CS_2, for example, inhibits growth in rats.

Particulate loading of the atmosphere from coal and refuse piles and the combustion of coal and acid mine drainage resulting in groundwater contamination continue to be acknowledged as major problems associated with mining, processing, and storing of coal.

There is also an acknowledged inadequate data base for determining the health effects, present or potential, of the trace elements from coal combustion or conversion plants. Important synergistic effects between certain coal-derived metals and other inorganic and organic substances can be anticipated and may also prove important in health effects assessments. It is also recognized that in regard to food and water intake, particularly as affected by ash settling ponds and landfills, no toxicological assessment of trace elements or radionuclides is feasible at this time.

However, it must be recognized that the large number of chemical agents that can be potentially responsible for the spectrum of adverse reproductive outcomes, as well as the many possible avenues of human exposure, makes it vital that a systematic procedure to detect associations be considered. There have been various attempts to describe the relationship between exposures and outcomes and their interactions (Palmer 1976; Anon 1973; WHO 1967; Wilson 1964; Flynt 1976).

Palmer (1976) has recently described an assessment of current screening test procedures. It was suggested that if attention were concentrated not on the inconsistent malformations but on more consistent embryopathic effects which in one form or another are always associated with malformations, the predictive value of the screening tests would appear in a more favorable light. Hence, even if malformations are not determined, the range of conditions (dosages) in which they might occur can be determined. Such information, used in conjunction with that obtained from other preclinical studies, can then form a reasonably sound basis for extrapolation to man (Morris et al. 1979).

Flynt (1976) recently reviewed epidemiologic techniques for assessing teratogenic effects. Employing a variety of approaches, epidemiology can develop or test hypotheses concerning possible causes or through surveillance provide data useful for a variety of purposes.

Recommendations:

1. Investigations of possible direct and synergistic effects between coal-derived metals and other inorganic and organic substances as related to reproductive effects should be performed.

2. The potential of diesel exhaust to result in reproductive effects should be studied.

3. Reliable predictive procedures are needed to evaluate injury to reproductive processes, especially for measuring physiological disturbances.

4. Development of systematic methods for identifying spontaneous abortions is needed.

5. Investigations on the effects of placental transport be undertaken for the major coal-derived metals and metalloids as well as the possible interactions (e.g., cadmium and calcium).

6. Studies are required to elaborate the factors and conditions influencing transport and metabolism of coal-derived toxicants by the placenta and its response to them.

7. Additional studies should be undertaken to elaborate the effects of toxicants coal-derived metals, and metalloids on

nutrient movements across the placenta and the means by which these agents are transported between mother and fetus.

8. There is an acute need for both more definitive and economical test systems for assessing and validating reproductive dysfunction risks. Research efforts in development of *in vitro* test systems utilizing organ and whole embryo culture should be undertaken.

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